ASTRONOMY

May 1983
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Celestial Debris

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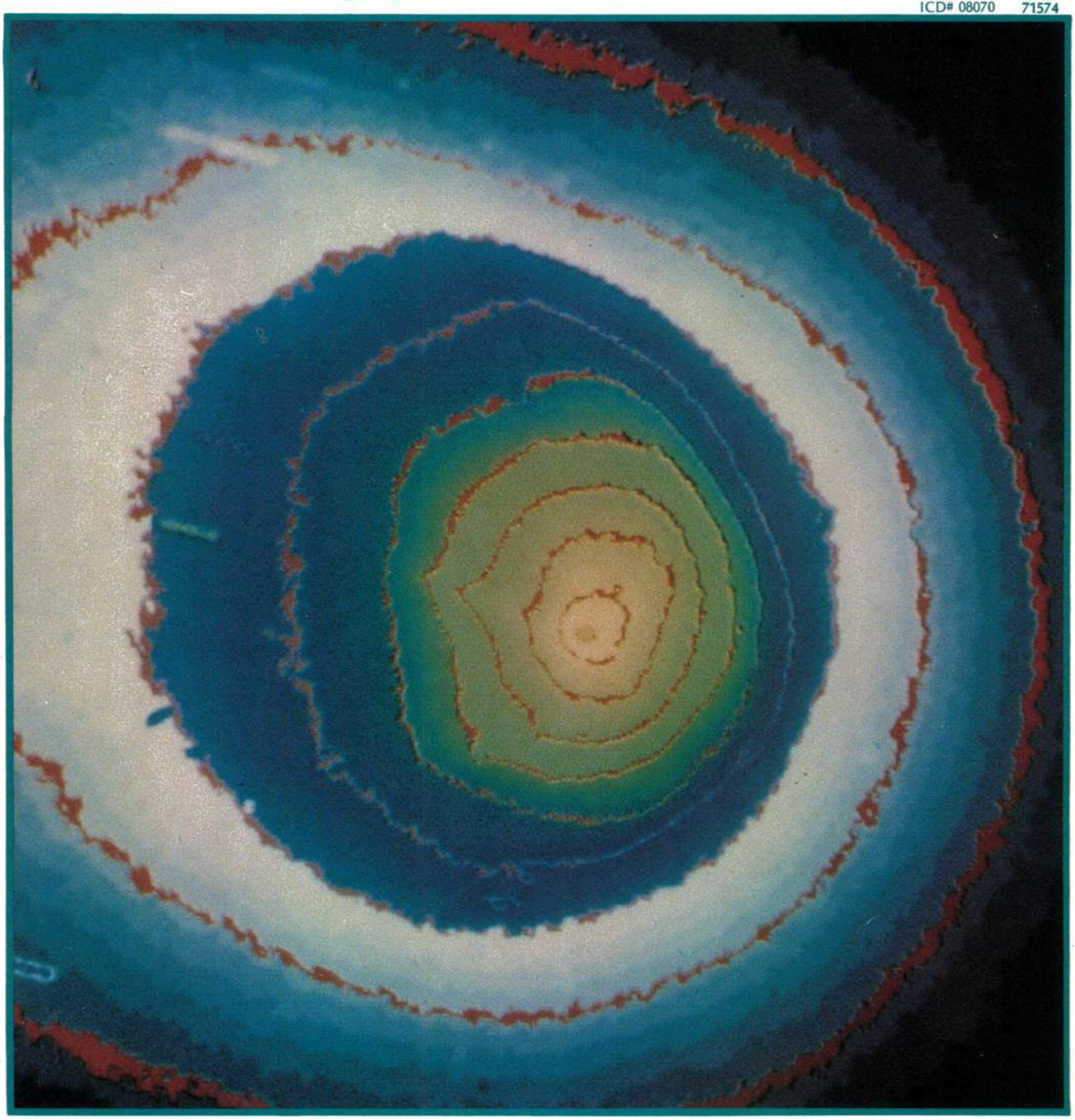

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Telescopes Shown: *(top) Meade 8" Model 2080 with optional photographic systems, including 4" Schmidt-Cassegrain Photo-Guide Telescope; and (bottom) Meade 10" Model 2120 with optional 2" f/12 Photo-Guide Telescope.*

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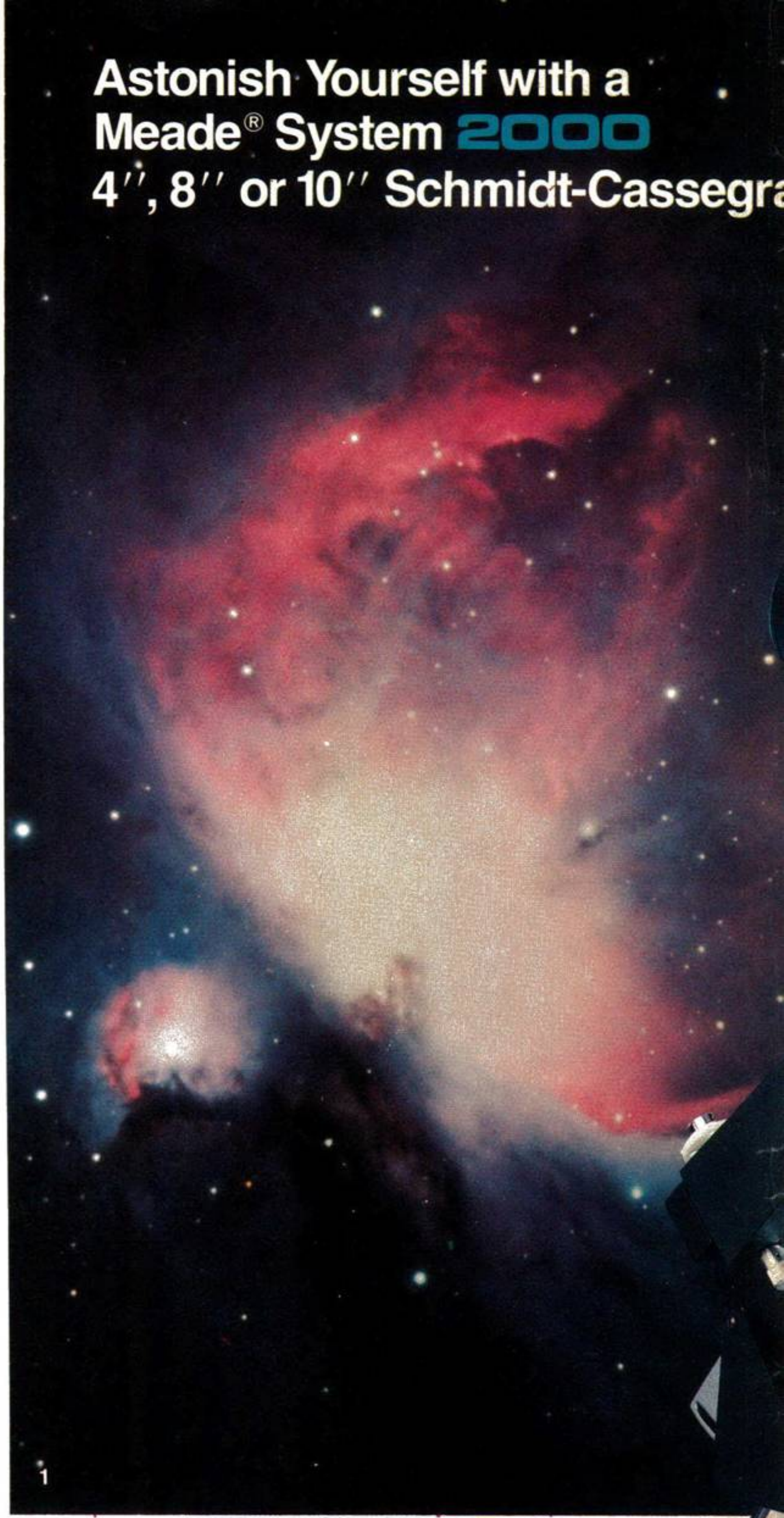

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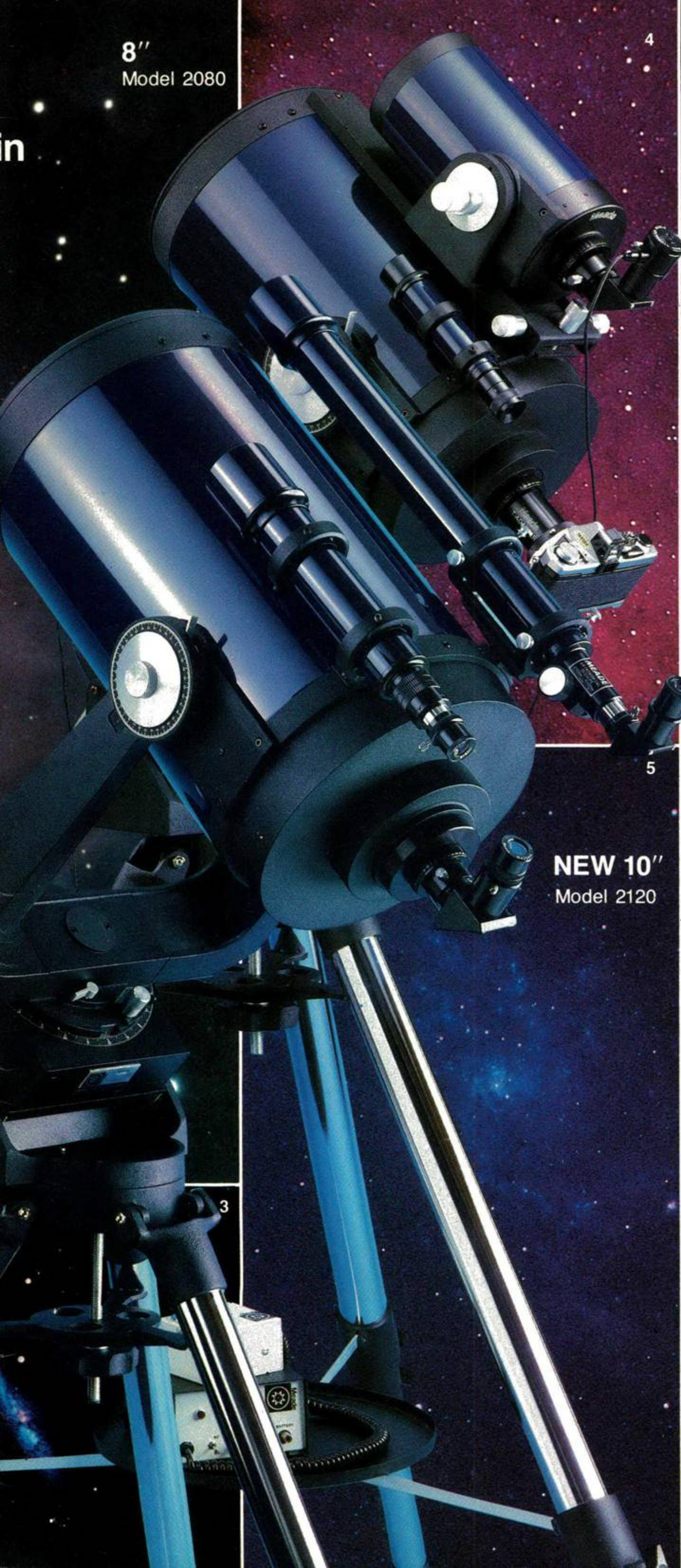

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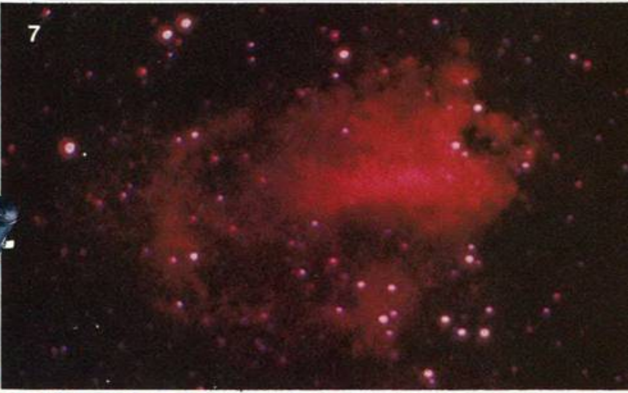
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All astrophotographs shown on these pages were taken through off-the-shelf, unmodified Meade 8″ Model 2080 Schmidt-Cassegrain telescopes. For further technical details on these and many other astronomical photographs, send for your free copy of the Meade Schmidt-Cassegrain Astrophoto Brochure. (Alternately, the complete Meade 52-page General Catalog is available at $3.00 by First Class Mail and includes the Astrophoto Brochure at no additional charge.)

Key to Photographs
1, 2, 3, 5—Leo Henzl; **4, 7**—Emery Hildebrand; **6**—Paul Roques; **8**—John Sanford

1. Orion Nebula M42; exposure time 50 mins. **2.** Andromeda Galaxy M31; 60 mins. **3.** Galaxy M82; 60 mins. **4.** Milky Way in Sagittarius (50mm piggyback photo). **5.** Spiral Galaxy M33; 75 mins. **6.** Spiral Galaxy M51; 90 mins. **7.** Omega Nebula M17; 40 mins. **8.** Moon—Clavius region.

ASTRONOMY

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Cover: Although comets, asteroids, and meteorites rank among the smallest members of the Sun's family, these pieces of celestial debris attract intense interest from planetary scientists. ASTRONOMY's lead feature this month investigates what these strange objects have to tell us about the early days of the solar system. The cover, a computer-processed image made from four photos taken of Comet Halley in 1910, clearly reveals asymmetric shells of gas in the comet's coma — clues to the structure and behavior of its hidden nucleus. Photo courtesy of D.A. Klinglesmith, Goddard Space Flight Center. These pages: The streak of a Perseid meteor — a tiny bit of debris littering the orbit of Comet Swift-Tuttle. Photo by Rick Schmidt.

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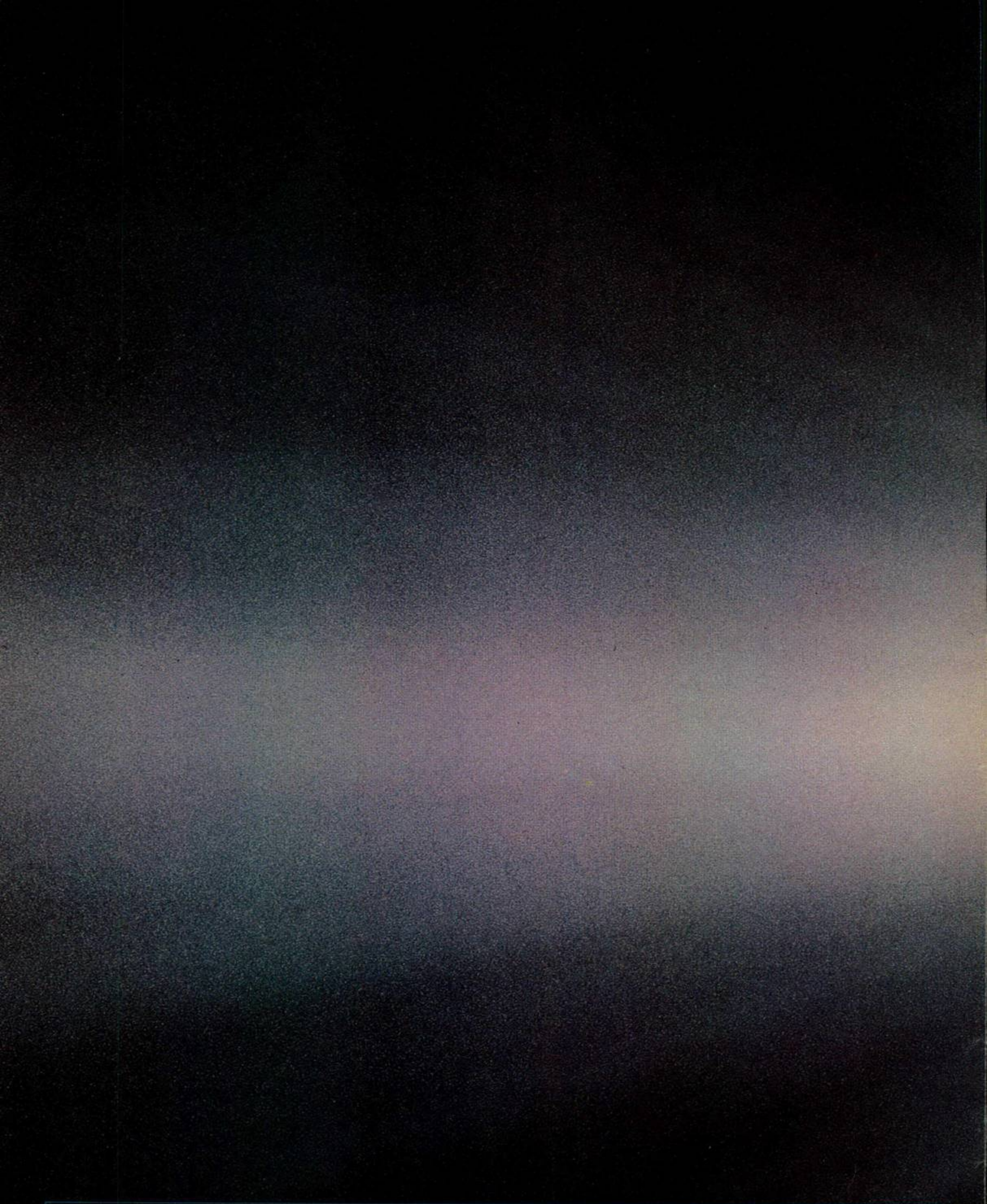


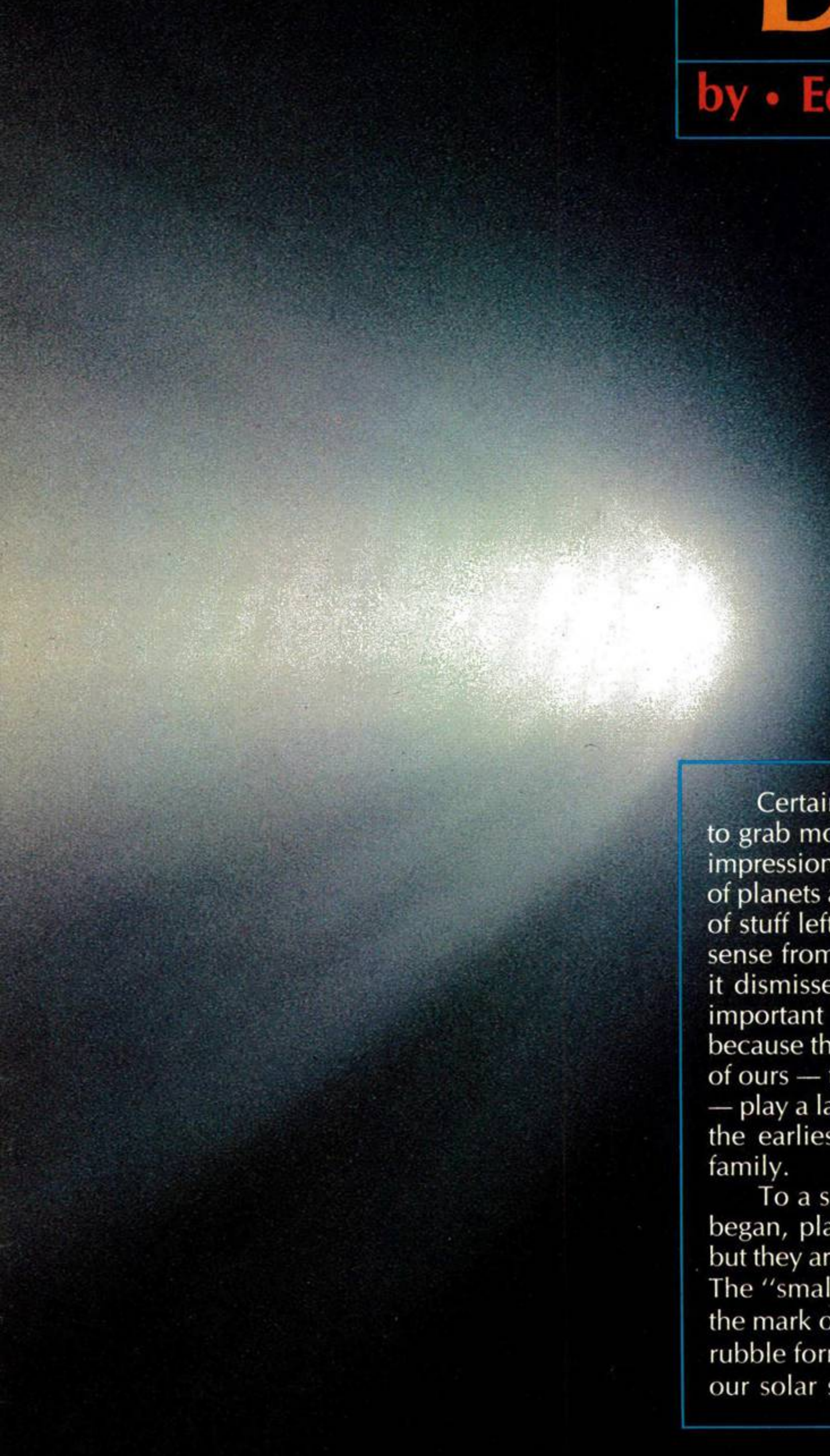
About as far from the Sun as Jupiter, a 10-kilometer diameter comet nucleus is warm enough to begin forming its gaseous coma. Though small as yet, the coma will grow to be several hundred thousand kilometers across by the time the comet comes as close to the Sun as the Earth.

Painting by Mark Paternostro

PATERNOSTRO © 83

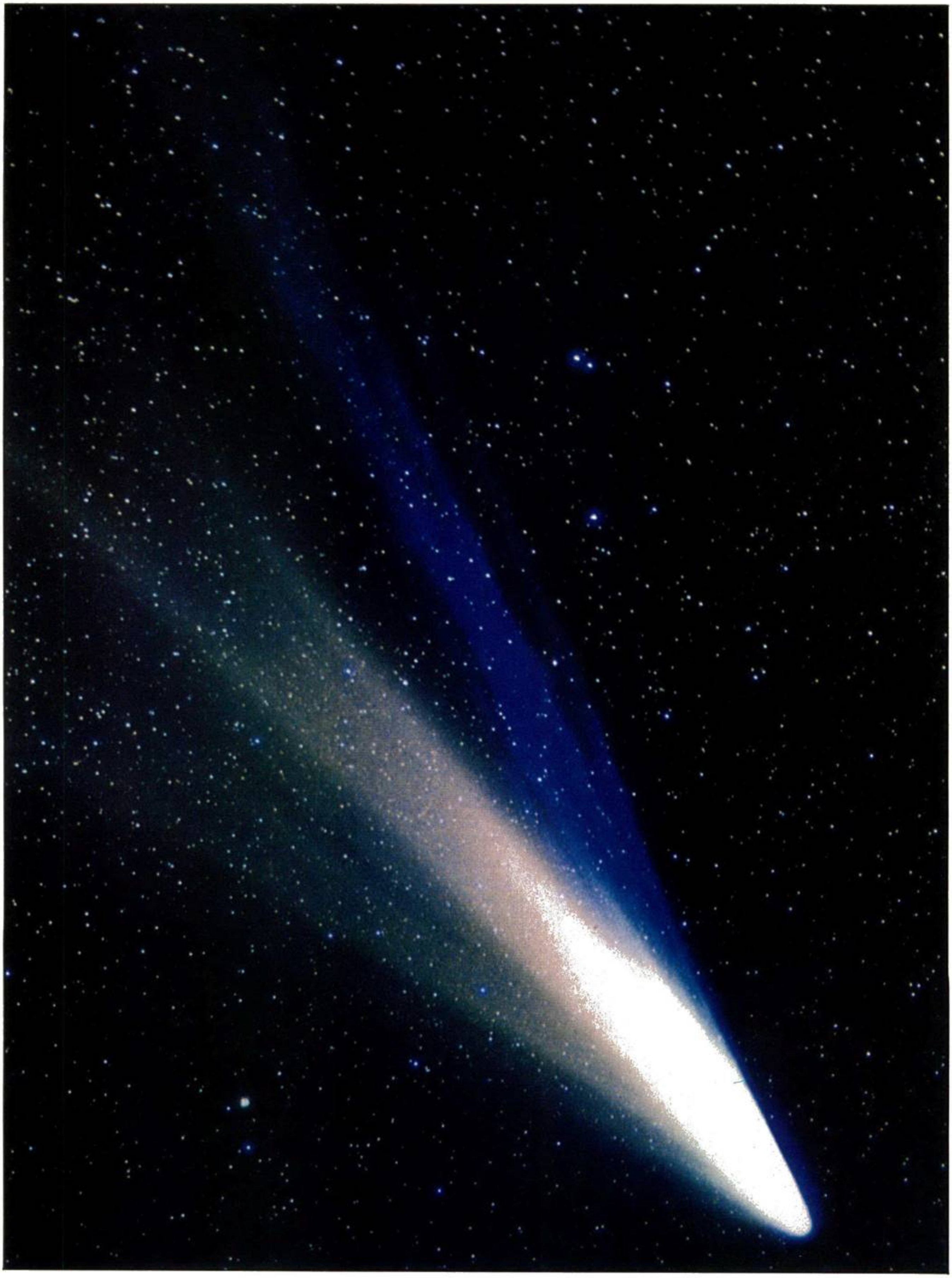
Celestial Debris

by Edward J. Ciaccio



Certain members of the solar system seem to grab most of the attention: you often get the impression that the Sun's family consists entirely of planets and moons, with a few negligible bits of stuff left over. And while this makes a lot of sense from the point of view of size and mass, it dismisses some of the most fascinating and important members of the solar system simply because they are small. Yet these tiny neighbors of ours — the comets, asteroids, and meteorites — play a large role in our attempts to understand the earliest beginnings of the Sun and all its family.

To a scientist interested in how the system began, planets are important objects to study, but they are far removed from their original state. The "small stuff," on the other hand, still bears the mark of its origins. Thus these bits of cosmic rubble form an important link with the dawn of our solar system.



The coma of a typical comet will stream off to form two tails — one of dust and the other of ionized gas. Here Comet West's gas tail shows a bluish color, while the dust tail, smeared to one side by the comet's motion, shines yellow-white with reflected sunlight. Photograph by Ronald Royer.

Comets

No one has yet looked upon the bare surface of a comet. Through a telescope or with the naked eye, what we see is the *coma*, a cloud of volatile atoms, ions, and molecules, that forms the head of the comet, and a *tail*, which is composed of ions and dust particles. The coma and tail are large, usually extending for hundreds or thousands of miles. The hidden core of the comet, its *nucleus*, is the source for the material that forms the coma and tail, and is the only solid part a comet has; it is thought to be barely 10 kilometers across.

Comets are unique among solar system objects, since they originate far out beyond the orbit of Pluto. At a distance of perhaps 50,000 astronomical units (one AU is the distance from the Sun to the Earth) lies a cloud of fragile, frozen spheroids of ice, called the Oort cloud. (To visualize 50,000 AU, let one inch equal one AU; on this scale, the Oort cloud lies three quarters of a mile away!) The temperature in the cloud, from which the Sun would appear as bright as Venus is now in the evening sky, hovers close to absolute zero (-273° C) — the coldest temperature possible.

On occasion, the feeble gravitational nudge of a distant star may perturb one of the spheres out of its slow orbit and start it on a long fall toward the inner solar system. The sphere's subsequent orbital path can have a variety of shapes. It can be very eccentric (elongated), so that it passes close to the Sun. Or it can be more circular, in which case the comet may remain too far out ever to be discovered. And the orbit can be hyperbolic, in which case the comet will have enough energy to leave the solar system entirely once it passes close to the Sun. Most comets have eccentric but closed orbits; this means that they approach very close to the Sun, yet will return years, centuries, or even millennia later for another pass.

Cometary orbits may be prograde or retrograde — that is, in the same direction as or opposite to the revolution of the planets around the Sun — and comets may penetrate the inner solar system at any angle. This has led to the theory that the Oort cloud has a shell-like or spherical structure — if it were disk-like, for instance, the range of angles of inclination would be more limited.

As the comet encounters the Sun, its frozen ices will warm up. The ices with low boiling points, such as hydrogen cyanide and methyl cyanide, will begin to boil off the nucleus while the comet is still far from the Sun — near the orbit of Jupiter, say. Since comets are made of half ice and half dust, these ices will liberate dust particles when they vaporize. Near Earth's orbit, water ice will vaporize and will release more dust. By the time a comet has come this close to the Sun, an observer will see a well-developed coma and tail formed of materials from the nucleus.

But comets don't lose all their ices in a single pass around the Sun. One reason for this is that layers of dust insulate the ice, preventing solar radiation from penetrating deeply. Furthermore, a chemical structure called a clathrate may form in which the water-ice component — not as volatile as the other constituents — governs how fast the other ices escape and prevents a disproportionate loss of the more volatile material. In all, the amount a comet nucleus loses on each perihelion passage adds up to a layer about three meters thick.

Although a comet nucleus remains well-hidden at optical wavelengths, one group of scientists has "observed" the nucleus of Comet Encke by radar. Analyzing the returned signal, they found the diameter of the comet lay between 0.8 km and 8 km. Unfortunately, only one comet has been observed in this way, because the technique doesn't work with comets that remain far from Earth.

Could we then examine a nucleus while the comet lay far enough out not to be shrouded in its coma? The problem here is that few comets are discovered while they are far enough away from the Sun to still be cold; more important, an object 10 km in diameter that lies 10 AU away is merely a dimensionless point of light in even the largest telescopes. There *is* hope that the several spacecraft scheduled to approach Comet Halley in 1986 will get close enough to view the nucleus. But Halley is a young comet that still has a plentiful supply of volatile ices — its coma will be thick and bright, and the nucleus may well remain unseen even at closest encounter. We would have a better chance of viewing the nucleus of an old comet — "old" in the sense that it has passed close to the Sun many times and has lost most of its volatiles. What remains is probably a porous object composed of dust grains and some water ice; such a nucleus may look rather like a roughly spherical piece of coral.

A typical cometary coma stretches perhaps 200,000 km across, about half the distance between the Earth and Moon. The coma is a sort of atmosphere that surrounds the nucleus — in some ways like the Earth's atmosphere, only much thinner. It contains dust grains, and gas molecules and ions in about equal proportions. The coma is most developed on the comet's sunward side because the materials are heated and vaporized faster there.

Many types of atoms and molecules have been found in comets by examining their spectra: organic and inorganic, metals and ions. Silicate minerals, found in rocks and sand on Earth, make up a large portion of comet dust grains. These grains may also be comprised of carbon, the material found in charcoal. Ionized atoms and molecules are those which have lost one or more negatively charged electrons and have become positively charged. The energy to split the atoms comes from absorbing solar ultraviolet radiation.

The most spectacular part of a comet is its gas, or ion, tail. An ion tail generally points away from the Sun, but its electrically charged gases interact with the stream of ions from the Sun called the solar wind. These solar ions, together with ions from the comet, generate magnetic fields that may produce "kinks" or knots of higher density in the ion tail, as well as voids where there are fewer ions than normal. The overall effect is to push the cometary ions in the direction that the solar wind is traveling — straight away from the Sun.

These interactions hint that comets are not always as quiescent as they appear. Often, planetary scientists detect sudden changes in brightness in the coma. There are a number of explanations for this, but perhaps the most widely held is that the cometary ice and dust is not uniformly mixed. The ice forms in subsurface pockets and is suddenly expelled in little explosions or jets when the surface material over it boils off.

Besides gas tails, most comets — though not all — also develop dust tails. The dust particles initially stream away from the nucleus along with the gas to form the coma, but soon afterward the dust is pushed out of the coma by radiation pressure. The light from the Sun that reflects from the dust grains gives them a little push, and while you will never feel a tiny push when *you* stand in full sunlight, cometary dust particles are small enough to be affected. Planetary scientists have found — by measuring the way the particles reflect light — that they are about a thousandth of a millimeter (one micron) in diameter. Dust tails tend to be more diffuse and often are gently curved, as the particles slew to one side due to the comet's motion.

But where does the dust expelled from a comet go? Some of it joins the dust that pervades interplanetary space, and some may be caught by the gravitational fields of planets such as Earth. Micrometeorites in the form of *Brownlee particles* (named after their discoverer) have been found in the Earth's stratosphere. These micrometeorites are about five microns (five thousandths of a millimeter) in size, approximately the same as the dust grains in the coma of a comet.

Laboratory studies of these diminutive dust particles show them to be fine-grained and porous. The grains can be single crystals or aggregates of smaller grains. Many are amorphous, having no crystalline structure. The grains are mainly composed of carbon compounds, metal-sulfides, and silicates. Such a composition is consistent with material that has not been strongly heated since the formation of our solar system — thus it differs substantially from the materials found in the planets and satellites.

Asteroids

Most of the more than 2,500 known asteroids are spread out in a belt between 2.2 and 4 AU from the Sun. This region is a transition between the rocky inner solar-system planets and the outer gas-giant planets. Asteroids tend to have orbits that are modestly inclined relative to the planets' orbits, and asteroidal orbits are also somewhat more eccentric than most planetary orbits.

One way of classifying this space rubble is by its spectral characteristics. In the laboratory, planetary scientists compare spectra of known metals and minerals with asteroid spectra to determine their composition. About 75% of all asteroids are the C-type; these dark objects (3.5% albedo) concentrate at about 3.2 AU, toward the outer regions of the belt. Most inner-belt asteroids (near 2.2 AU) are S-type; these are thought to be composed of rocky material and constitute perhaps 17% of all asteroids. Other asteroid types are not as common as the C- and S-types. Asteroids can also be classified by their orbital elements. Those with the same orbital elements may be debris from a single large asteroid that broke up. Such objects constitute a family of asteroids; there are about 100 of these families known.

The big question puzzling researchers is, where do they come from? Are they the remnant of a planet which was obliterated in an explosion? Probably not — first of all, if you were to gather all the asteroids together, you would not even make an object as large as our Moon — although the biggest asteroid (Ceres) has a diameter of 1,025 km. The total mass of all the asteroids comes to about 5% of the Moon's mass.

In the second place, the distribution of types of asteroids is consistent with their composition. For the most part, only rocky objects could form in the inner solar system while the Sun was a hot star, early in its history. Carbonaceous, icy, and gaseous materials could not condense in those hot regions. Thus we see rocky metallic worlds close to the Sun and gassy volatile-rich worlds farther out. In the transitional asteroid belt, planetary scientists have also found systematic differences: asteroids closer to the Sun appear to be rockier and more metallic, while those farther out contain lighter carbonaceous and hydrated minerals.

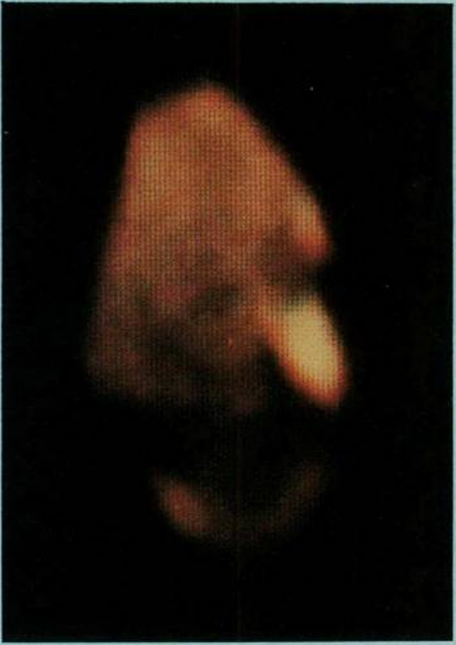
It seems unlikely that a large planetoid could be broken up and yield such a conveniently graded assortment of minor worlds from its debris. More probably, there never *was* enough material in the asteroid belt to become a full-fledged planet. Rather, the mass that collected there tended to stay in the form of small bodies — and in all likelihood, Jupiter's immense gravitational influence worked to keep them small.

Jupiter still continues to exert its effects: the asteroid belt is not a continuous swath. At several discrete distances from the Sun, there are spaces called Kirkwood gaps (after the American astronomer Daniel Kirkwood who discovered them), where no objects seem to orbit. The Kirkwood gaps are places where an asteroid would orbit the Sun in a time that has some simple numerical relationship to Jupiter's orbital period. What this means is that any asteroid orbiting in the gap will repeatedly feel a strong pull from Jupiter — and is soon perturbed out of the orbit.

But despite these "clearings," the overall density of objects within the belt is great enough so that, given billions of years, collisions among the asteroids will be significant. Since the average encounter speed would be about 5 km per second, tremendous impacts would result. Such impacts will pulverize at least part of each asteroid, and some of the immense amounts of finely broken material will gradually settle back onto these and nearby asteroids in a layer called regolith. Calculations show that layers of regolith as thick as a kilometer could form on a 100-km diameter asteroid. Very tiny asteroids have a gravitational field so negligible that only much thinner layers of regolith can be retained. The amount of regolith an asteroid has also depends on the strength of material from which it is made. Asteroids composed almost entirely of iron and nickel are very strong and suffer comparatively little damage in a collision with a more friable rocky or carbonaceous asteroid. Accordingly, most of the regolith found on metallic asteroids will probably be mineral material from the objects that collided with them.

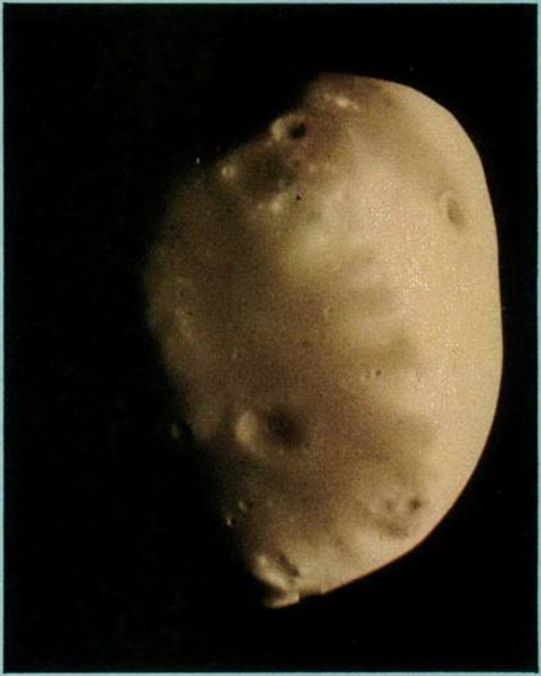
Although there is a gradation within the belt, the composition of asteroids is less simple than it seems. Some, for example, are almost entirely metal and some

Asteroids That Wandered Astray?

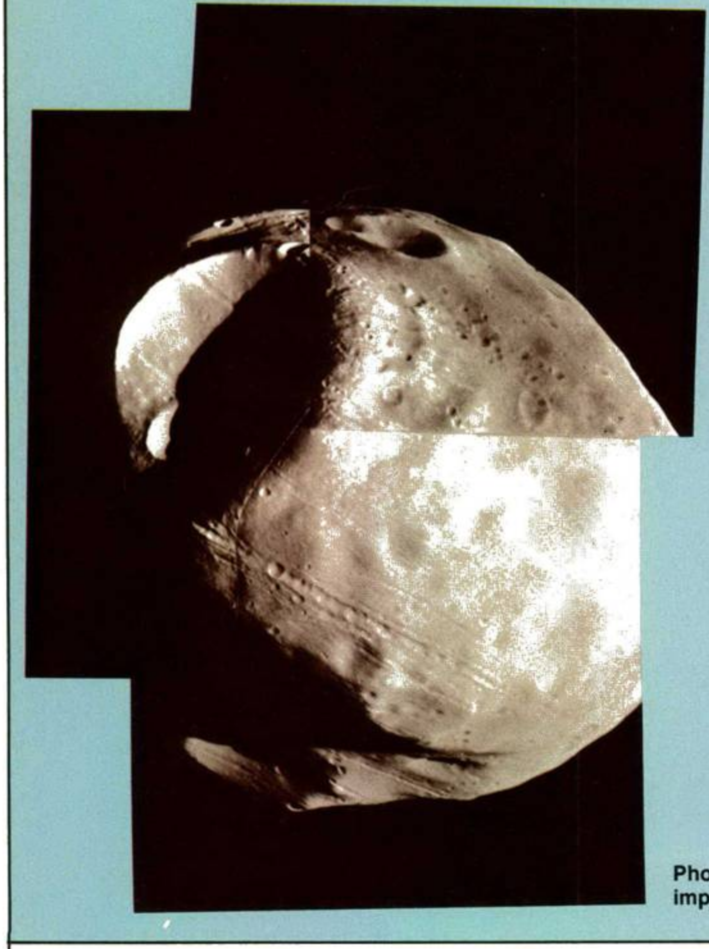


Amalthea orbits Jupiter; it is rocky and cratered and has similarities to certain types of asteroids.

Phoebe is Saturn's outermost moon; it orbits backward and shares spectral characteristics with some asteroids.



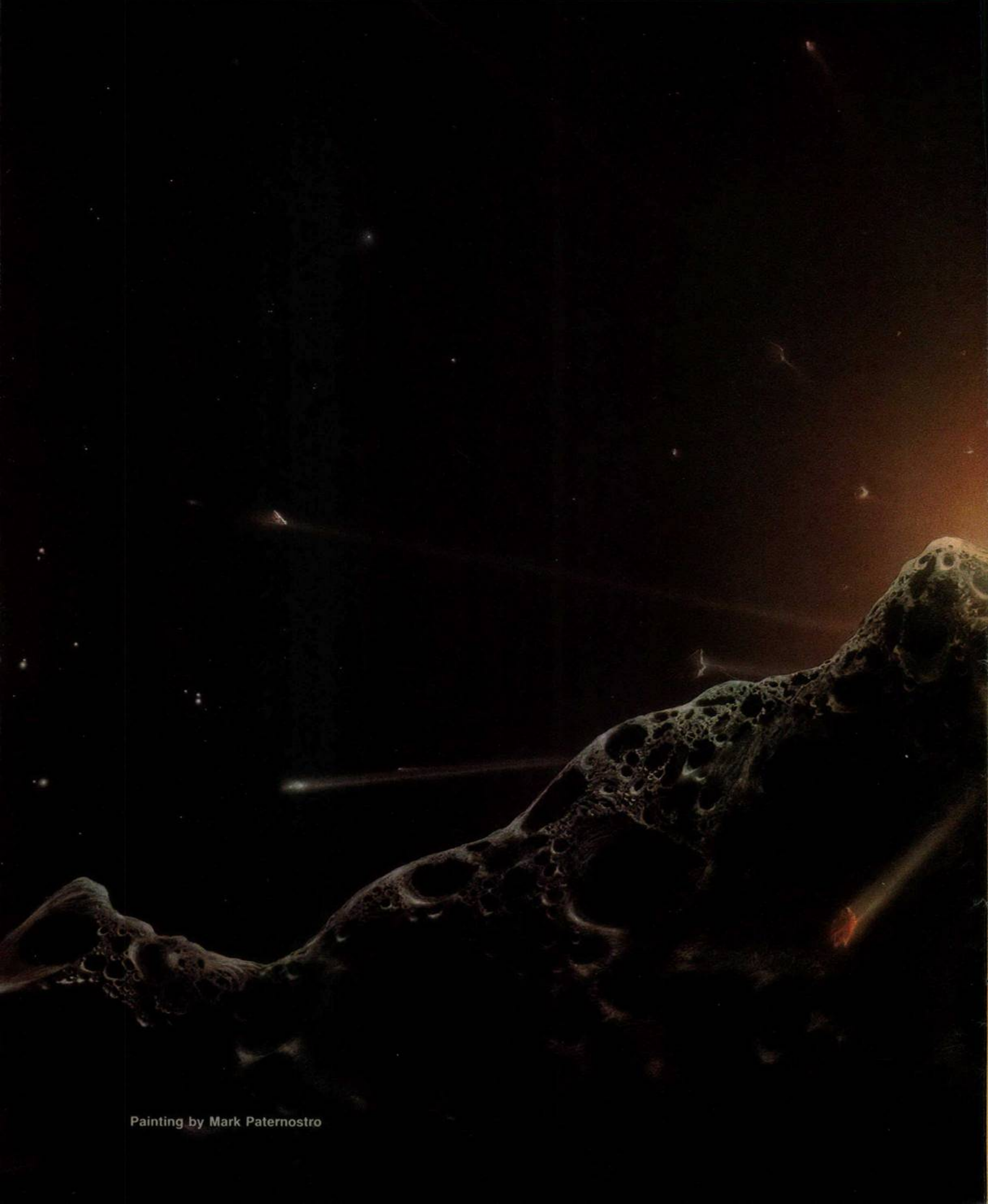
Deimos, another rocky fragment, is Mars' outer moon; its surface is inexplicably smooth.



Phobos is the inner of Mars' two moons; rocky and pitted by impacts, it has the photometric properties of an asteroid.

All photos JPL/NASA

Given billions of years, collisions between asteroids are inevitable — and may account for much of the diversity we see today. Such impacts can break up bodies, mix their components, and reassemble them in new ways — or may shatter them into relatively homogeneous fragments.



Painting by Mark Paternostro

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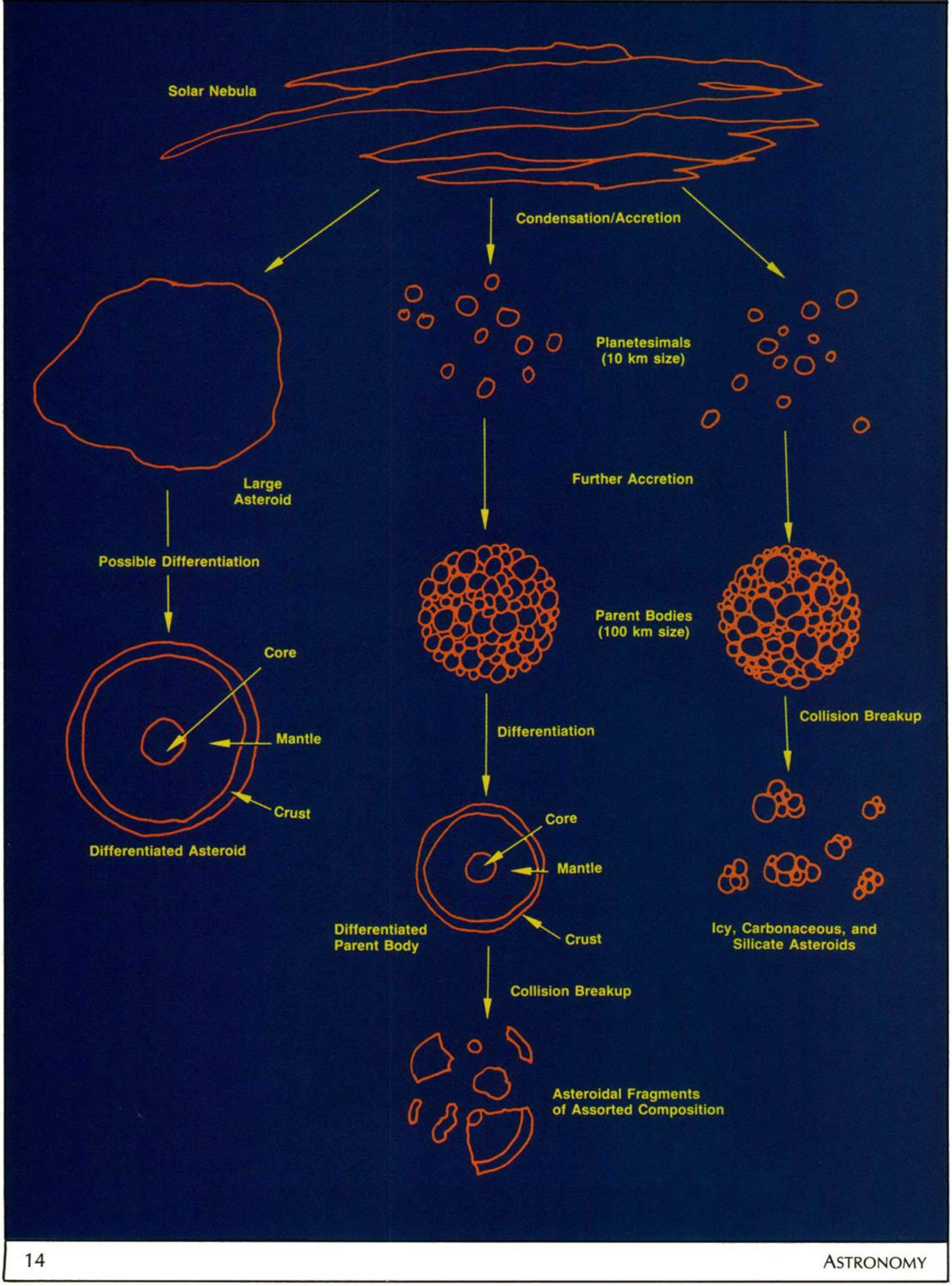
Asteroid Evolution


Solar Nebula
Condensation/Accretion
Large Asteroid
Planetesimals (10 km size)
Possible Differentiation
Further Accretion
Core
Mantle
Crust
Differentiated Asteroid
Parent Bodies (100 km size)
Differentiation
Collision Breakup
Core
Mantle
Crust
Differentiated Parent Body
Icy, Carbonaceous, and Silicate Asteroids
Collision Breakup
Asteroidal Fragments of Assorted Composition

are almost entirely rock. To understand this, we must look at the current theories of asteroid formation and evolution. As we saw, in the early days of our solar system, a hot nebula of gas and dust called the pre-solar nebula surrounded a very hot proto-Sun. The small amount of material present in the region that is now called the asteroid belt condensed into solid matter as the Sun began to cool. It then accreted into spheres, called planetesimals, approximately one kilometer in diameter. These planetesimals aggregated by collisions and mutual gravitational attraction to form larger spheres, called parent bodies, which averaged perhaps 100 km in diameter. Prior to aggregation, some of the planetesimals were heated, perhaps by short-lived radioisotopes and perhaps by electrical inductive heating from a strong, early solar wind as well.

In space, when a metal-and-rock boulder melts, the densest constituents (mainly iron and nickel) sink to the center and form a core, while the lower density silicate rocks float to the top to form a mantle. If any ices and carbonaceous minerals are present, they will coat the exterior of the mantle as a crust. This process is called differentiation. But not all asteroids have undergone it: scientists think a few asteroids (Ceres is one) may have accreted directly from the early nebula into their present form without going through the planetesimal stage and without being differentiated.

At the inner belt region, formed at higher temperatures, mainly rocky and metal materials are present, and parent bodies had large metallic cores. Over the 4.7 billion year age of the solar system, most of these parent bodies have been fractured by collision. In some cases, the bare metallic cores may be exposed — which might account for M-type asteroids. Farther from the Sun, where the nebula was cooler, asteroids of other types contained different concentrations of rock, metal, carbonaceous materials, and ices. These, too, have been fragmented by collisions. The result might well be the mixed-up gradation of types that we observe.

Not all the asteroids are found in the main belt: the Trojan asteroids orbit the Sun at two of Jupiter's Lagrangian points — places in Jupiter's orbit (L4 precedes Jupiter, while L5 trails) that are equidistant from both the Sun and Jupiter. Any object that wanders into these positions will tend to remain, since the gravitational forces of the Sun and Jupiter balance there. Most Trojans have very low albedos, as do many outer jovian satellites; this hints that both Trojan asteroids and outer jovian moons may once have been asteroids in the main belt. Perturbed out of their orbits by near-misses or collisions, they were captured by Jupiter.

Other groups of asteroids, called Apollo-Amor objects after the two prototype bodies, have orbits that come inside that of the Earth. Conceivably, one of these massive objects could collide with Earth, but the chance is minuscule. The Apollos and Amors pass close enough to Earth and other inner planets so that either a collision with a planet takes place or — and this is by far the more likely occurrence — they are ejected from the solar system. Since the population of these objects tends to dwindle over what, geologically speaking, is a very short timescale, Apollo-Amors must be continually replenished with new members from the asteroid belt to maintain the population we see today.

Asteroids are so small and so far away that even with the largest of telescopes, they appear only as points of light. Must we wait, then, for an asteroid reconnaissance mission to see what these worlds look like? Perhaps not, because the two martian satellites, Phobos and Deimos, may in fact be two former asteroids. Their spectra and albedos are both similar to the dark, carbonaceous C-type asteroids.

Phobos (which measures 27 km x 22 km x 19 km) and Deimos (15 km x 12 km x 11 km) are much more interesting than their small sizes suggest. On Phobos, a great impact produced the crater Stickney, which is a fifth as large as the satellite itself. The collision may have been responsible for some strange grooves that radiate away from Stickney. These grooves are about 100 meters wide and 10 deep; farther from Stickney, a chain of pits extends away from the grooves. The grooves may be areas where a deep, wide fracture cracked the surface and was then partially filled by regolith. The chain-pits may be areas where the fracture is completely closed except directly below each collapse pit. Phobos has many craters covering its dark surface, and one tip of this cigar-shaped satellite always points toward Mars.

Deimos offers several contrasts: to the amazement of planetary scientists, this tiny moon has many giant boulders on its surface — yet its gravity is so weak that a person standing on the surface could throw one of these boulders off by hand! In addition, the actual surface material appears much smoother than on Phobos — again, a puzzle since dust should not settle on Deimos as readily as on the more massive Phobos.

Another curious case is the jovian moon Amalthea, a 240-km diameter, dark-red object, which orbits close to the planet. Its irregular shape suggests that it is composed of minerals, rather than ices (which would deform to a more spherical shape). Amalthea seems to have only a few light-colored craters, and its red surface materials may have been deposited by the volcanoes of Io, a nearby satellite. Though red in color, Amalthea is so dark that its albedo is similar to that of the C-type asteroids.

Two hundred twenty kilometers in diameter, Phoebe, Saturn's outermost satellite, is distinctive in that its orbit is retrograde (opposite to the other satellites). This suggests that it doesn't quite belong and that it, too, may be a captured asteroid. Like Amalthea, Phoebe's albedo mimics the C-type asteroids. Material from Phoebe lost by meteoric impacts could spiral toward Saturn and splatter onto nearby satellites — in fact, some of the dark material on one side of Iapetus may have come from Phoebe.

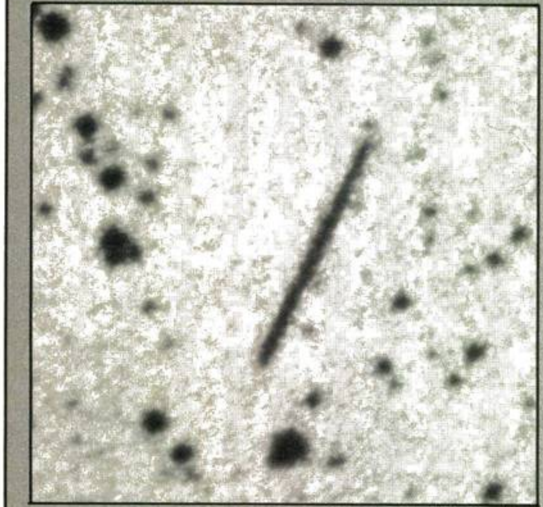
A relatively new process for seeing the fine detail in astronomical objects, speckle interferometry, has enabled scientists to resolve the disks of the larger asteroids. So far only vague markings have been detected, but one discovery has emerged — two asteroids (Pallas and Victoria) may have large satellites orbiting them. Such double asteroids may even be commonplace: Hektor, for example, has long been suspected of this. (See "Hektor — A Strange Asteroid?", ASTRONOMY, March 1979.) In some instances, the satellite may orbit so close to its primary that with conventional ground-based telescopes the system looks like a single elongated asteroid. Data from speckle interferometry suggest that eclipsing or even contact binaries exist. In the latter case, two massive boulders could be touching and rotating as a single system.

Celestial Debris

Lick Observatory

Comets (note: all values are for nucleus)

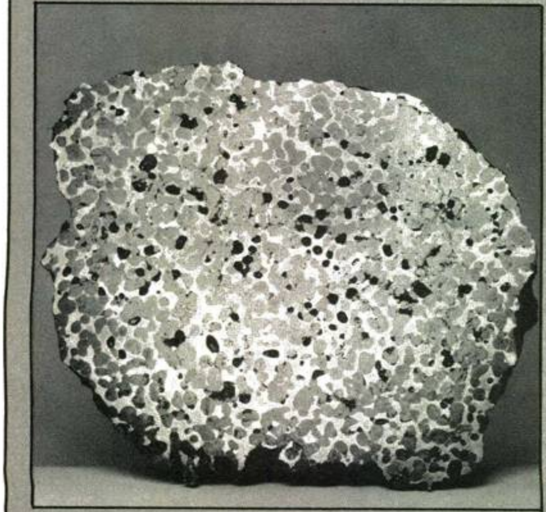
Diameter: 1 to 10 km
Mass: 10^{14} to 10^{19} grams
Density: 2 grams/cubic cm
Albedo: 60 to 70%
Composition: water, ammonia, methane, carbon dioxide, and other ices; carbon and silicon dust
How studied: visual, UV, IR, radio and radar; photometry, polarimetry, and radiometry



E. Helin/Caltech

Asteroids

Diameter: a few centimeters to 1,025 km
Mass: 10 to 10^{24} grams
Density: 2 to 3 grams/cubic cm
Albedo: range from 3 to over 20%
Composition: varies: metallic, silicate, and mixtures of both
How studied: visual, UV, IR, radio and radar; photometry, polarimetry, and radiometry



American Museum of Natural History

Meteorites

Diameter: microscopic to several meters
Mass: micrograms to 10^7 grams (largest yet)
Density: 2 to 8 grams/cubic cm
Albedo: 3 to over 30%
Composition: varies: metallic, silicate, and mixtures of both
How studied: laboratory analysis: chemical, optical, etc.

Meteorites

Meteorites — rocks from space — fall upon the Earth in a continuous rain. The smallest *meteoroids* (small solid objects in space) are microscopic in size. After encountering the Earth, they float through the atmosphere as Brownlee particles — which we discussed earlier in connection with comets. Slightly larger meteoroids, perhaps the size of a grain of sand, vaporize while entering the Earth's atmosphere and, at night, are seen as a bright streak of light called a *meteor*. With yet larger meteoroids, only the outermost layer melts and partially vaporizes; since they are large, some part usually survives the blazing trip through the atmosphere to crash to the ground as a *meteorite*.

How common are space rocks on Earth? About 18 are found each year (counting new falls and old finds), but usually only after substantial searching. In recent years, a particularly profitable locale has been Antarctica, where the cold, dry environment helps to preserve meteorites in their original condition. As the glaciers evaporate and the wind scours the snow and ice, they expose meteorites that fell ages ago.

A typical meteorite is often dark and smooth on the outside. Inside, planetary scientists find that they are far different in composition from typical Earth rocks. Despite the hot passage through the Earth's atmosphere, the interior of a meteorite can be studied because it remains unaffected by the fiery entry. Ablation tends to peel away the outer layers of a meteorite as it falls, and during the 15 seconds or so that it takes for a meteorite to fall from the top of our atmosphere to the ground, the heat of friction on the meteorite's surface cannot sink in fast enough to alter the interior. As a result, since the object has been "cold-soaked" in space, and since the last few thousand feet of its fall are relatively slow, the atmosphere actually *cools* the surface and most freshly fallen meteorites are distinctly cold to the touch.

Being able to pick up a meteorite and work on it in the laboratory has meant that we understand a lot more about these rocks from space than we do about their cousins, the asteroids and comets. Chemical composition, mineralogy, past history — all are open to our scrutiny.

One such property is the age of the meteorite — how much time has passed since its constituent minerals last crystallized. Scientists can get a good indication of how old a meteorite is by radiometric age dating. Radioactive isotopes present in a meteorite will slowly decay to produce "daughter isotopes" — new elements formed when an electron and proton in each atom combine to form a neutron. One such isotope, potassium-40, was incorporated into meteorites as they formed. Since then, potassium-40 has decayed to form argon-40. Another argon isotope, argon-39, has been present in unchanging quantities from the beginning. Therefore, by measuring the amount of argon-40 built up in the meteorite relative to the argon-39, a radiometric age can be determined on the principle that the more argon-40 present, the older the meteorite is. The age for one very primitive meteorite called Allende is about 4.6 billion years — nearly the age of the solar system itself.

Another "age" is the exposure age — the time that has elapsed since the meteorite was last buried in its parent body. When a parent body is broken up by collision, the resulting fragments may drift through space for millions or billions of years. After the collision, most of the fragments are exposed for the first time to cosmic rays — mainly energetic protons from the Sun. These protons smash into the atoms at or near the surface of the fragment and produce new atoms, such as neon-21, whose abundance can be measured in the laboratory. The more neon-21 found, the longer the meteorite has been in space on its own. Typically, most stony meteorites that fall to Earth have exposure ages of less than 60 million years, but some irons have been found with exposures of a billion years or more.

Meteorites are classed into three main groups: irons, stony-irons, and stones. The irons (5.7% of all falls) are composed almost entirely of metal: iron as their name suggests, plus significant amounts of nickel. Stony-irons are very rare (1.5% of all falls); some contain crystals of rock embedded in metal, while in others the metal and rock are more blended. Stones (92.8% of all falls) are the commonest; they contain carbonaceous and silicate minerals, as do terrestrial rocks, but in different proportions. Meteorites can also be classified in another way: differentiated meteorites (which include irons, stony-irons, and achondritic stones) are those that have been melted or changed by intense heat and pressure since their initial formation. Undifferentiated meteorites (chondritic stones) are rocks that have had little alteration since their origin.

When cut and polished, most iron meteorites display what is called a Widmanstaetten structure — a sort of crisscross pattern within the metal, which results from the growth of crystals composed of two different iron-nickel alloys. One alloy, taenite, contains more nickel than the other alloy, kamacite. The kamacite forms the long crystals that make up the Widmanstaetten structure. The widths of these crystals are determined by the nickel content of the meteorite, which in most iron meteorites varies between 6% and 16% by weight. When the bands of kamacite are more than five centimeters wide (indicating a low nickel content), the meteorite is called a hexahedrite. When the band widths are closer to one millimeter (due to moderate nickel content), the object is an octahedrite. A microscopic Widmanstaetten pattern indicates a very high concentration of nickel, and the meteorite is classed as an ataxite.

The alloys kamacite and taenite turn up not only in irons, but in practically all other meteorites, too, though in smaller amounts. The relative proportions and compositions of these alloys in a given meteorite indicate the rate of cooling of molten iron and nickel during formation. In some meteorites, for example, the proportions indicate a cooling rate of about 15° C per million years. Such a slow cooling rate is most likely due to the alloys forming in the molten core of a large, rocky parent body where they were well-insulated from rapid heat losses.

Perhaps the prettiest of space rocks are the pallasites, one of two types of stony-irons. Pallasites contain millimeter-to-centimeter-size crystals of a greenish silicate mineral, olivine, embedded in an iron-nickel matrix. The olivine is about twice as abundant as the iron-nickel matrix, which shows a Widmanstaetten structure. When cut and polished, pallasites resemble slices of pimento loaf. How did such peculiar rocks form? Just as asteroids are thought to have come from parent bodies, so are meteorites. At the interface between the molten metallic core and the silicate mantle of a still-hot parent body, olivine would crystallize out of the silicate magma as it cooled. Many of these crystals would be forced into the molten metal side of the interface by pressure from the outer regions of the parent body. Eventually, the molten metal/crystalline olivine portion would solidify, producing the material which we call pallasite. (This model is still a little controversial, however, since the tremendous pressures involved might have been capable of destroying the crystals.)

The other group of stony-irons are the mesosiderites, which have pyroxene as their principal rocky constituent. Unlike the pallasites, they do not have single crystals of the mineral embedded in the matrix. Instead, the pyroxene is fragmented and scattered as clasts throughout the metal. This suggests that a great impact or other shock event smashed the silicate and metal portions of the meteorite together while they were partially molten. Upon solidifying, they would resemble what we now see. Repeated impacts may have broken and re-welded the minerals many times over the lifetime of the mesosiderites. Such churned-up mixtures are called *breccias*.

Mesosiderites and some stony meteorites (eucrites, howardites, and diogenites) are all thought to have formed in space from the same solid material, called the "eucrite parent body." All of these meteorites are depleted in certain volatile elements, such as sodium, relative to the composition they would have if they had condensed from the pre-solar nebula without being melted and differentiated. The eucrites and diogenites are breccias composed of materials that are closely related chemically, while howardites are composed of inclusions that are not closely related.

But by far the largest proportion of meteorites are the *chondrites*. These are the most primitive of all meteorites — undifferentiated and closest to the composition of the pre-solar nebula, they have altered little since their accretion. (In this, they differ from the achondrites, the other group of stony meteorites, which have differentiated due to the effects of heat and collision.) Most chondrites contain *chondrules*: curious capsule-shaped or spheroidal, millimeter-size inclusions composed of silicate minerals (mainly pyroxene and olivine), which have melted and resolidified. In some meteorites, the chondrules are whole; in others, they have been shattered by impact.

Chondrites can be further classified by several additional criteria. For example, as their bulk carbon and water content increases, they are said to be enstatite, ordinary, or carbonaceous. Another characteristic is structure — enstatites are recrystallized agglomerates (solid debris that has adhered together). They also contain fractured chondrules, indicating that they have undergone shock from impacts. By contrast, most ordinary and carbonaceous chondrites contain unshocked, well-defined chondrules.

Planetary scientists have devised six petrologic types for chondrites. From type 1 to type 6, these classes become progressively less primitive: type 1 chondrites may contain up to 22% water and 5% carbon, whereas a type 6 will contain less than 2% water and carbon. Enstatites fall into the range of types 4 to 6, ordinaries are of types 3 to 6, and carbonaceous chondrites lie among types 1 to 4. Let's now look at these a little closer and then see what they tell about the meteorite's origins.

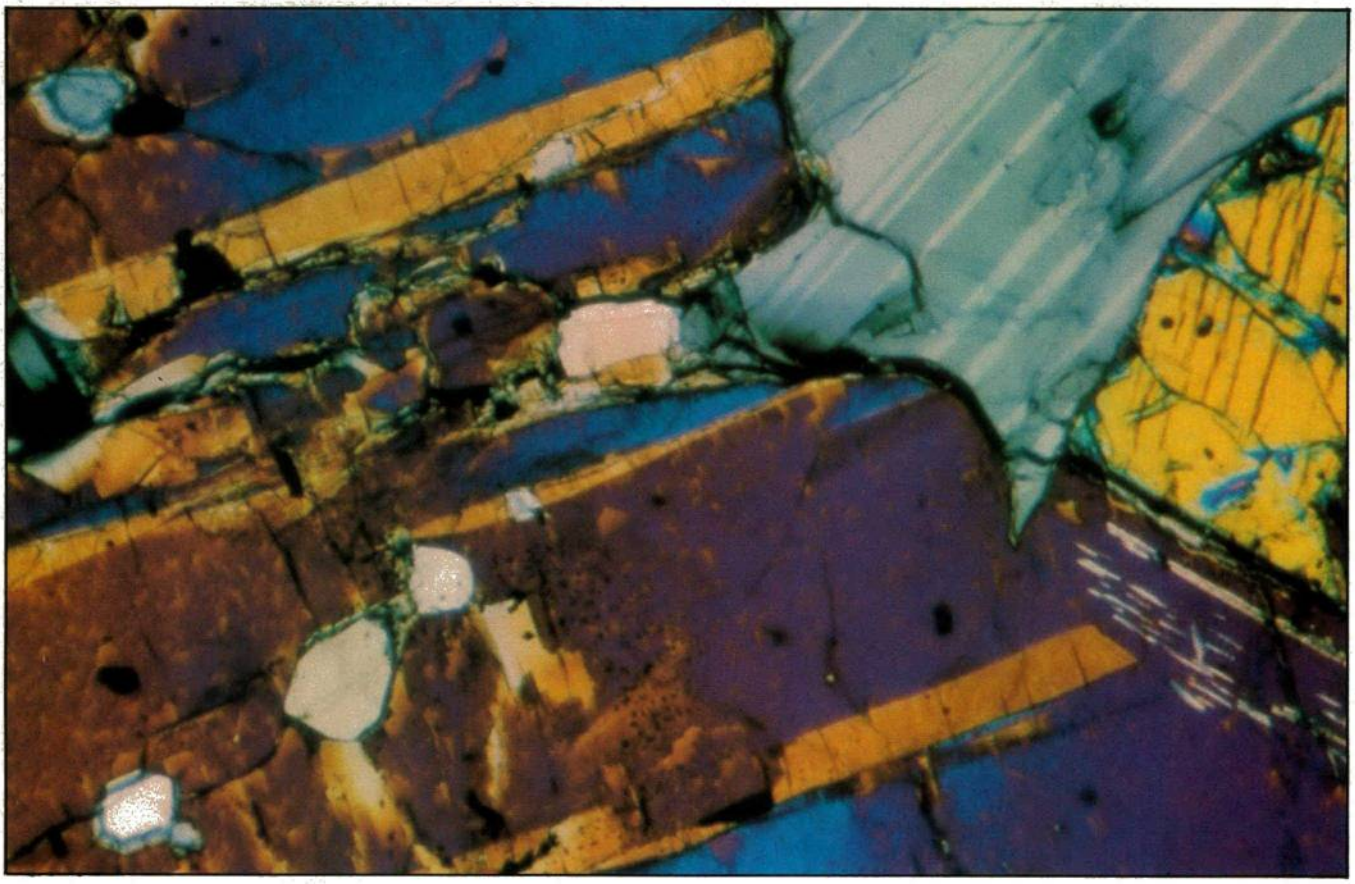
Enstatite chondrites are composed mainly of pyroxene, iron-nickel alloy, and troilite; in addition, they have a variable sulfur and iron content. Scientists think they have been "cooked" and metamorphosed at temperatures greater than 600° C. The ordinary chondrites are believed to have developed in space at low pressures and temperatures relative to enstatites — less than 1.5 atmospheres and 950° C. In them, the amount of metallic and oxidized iron varies in reverse proportion to each other: H-type have high concentrations of metallic iron and low concentrations of oxidized iron, L-type have lower concentrations of metallic iron and larger amounts of oxidized iron, and LL-type have the lowest concentrations of metallic iron and the largest amounts of oxidized iron. (The recent Wethersfield, Connecticut fall — see page 24 — was an L6 ordinary chondrite.)

Carbonaceous chondrites are the most primitive of all chondrites, being composed of chondrules, aggregates, and a fine-grained, volatile-rich matrix. These agglomerates appear to have condensed from the pre-solar nebula at very low pressure, essentially in vacuum. The carbon they contain is partially in the form of organic molecules — those that contain carbon and hydrogen, and often oxygen and nitrogen.

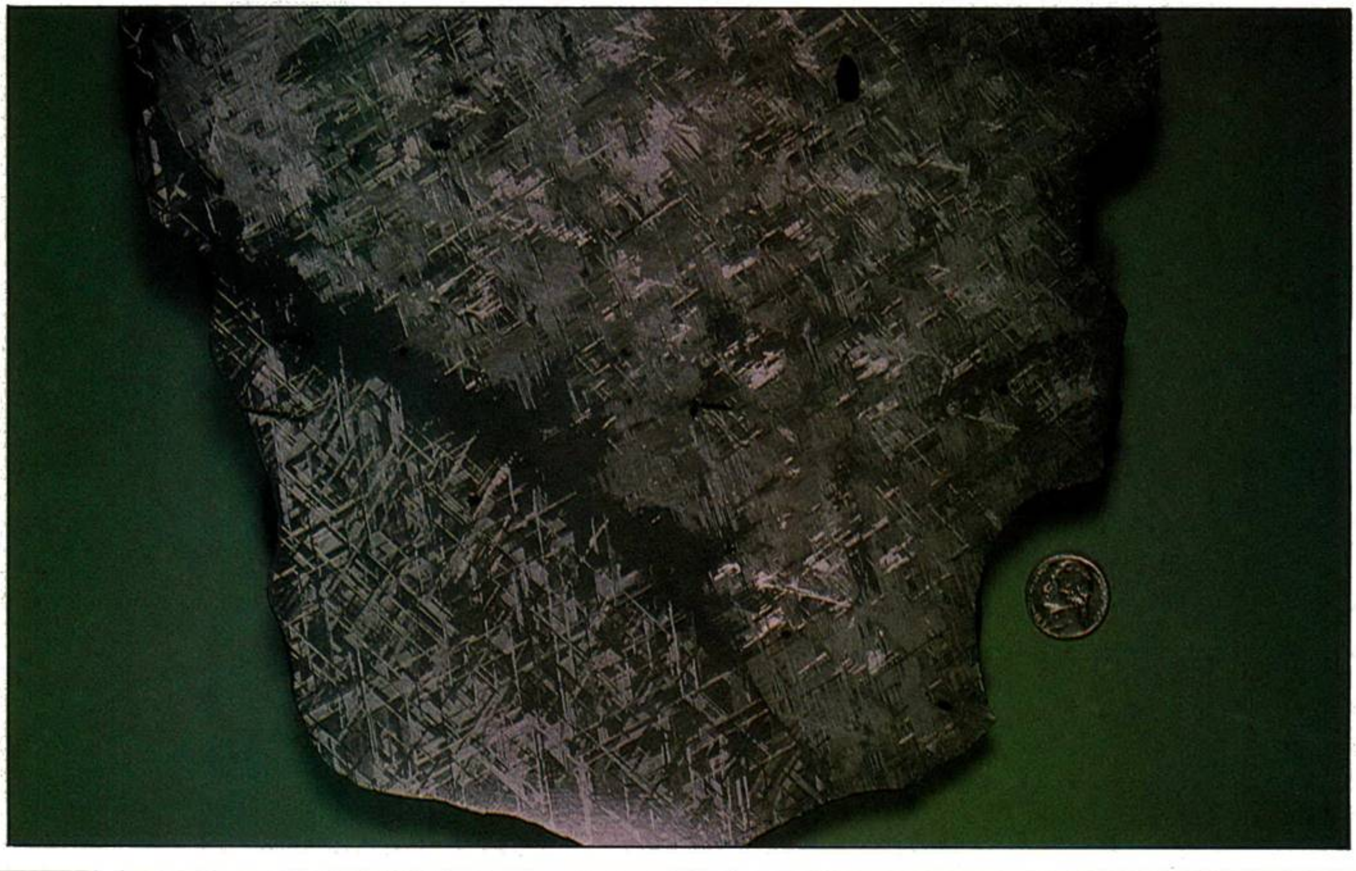
The most exciting and speculation-provoking aspect of carbonaceous chondrites lies in these organic chemicals, which take the form of long polymer-chains of carbon atoms. That some meteorites contain organic compounds is very important, because it indicates that the building blocks of life can form in the harsh and frigid environment of space. The chemical reaction responsible for the polymers takes carbon monoxide and hydrogen (which made up a great part of the pre-solar nebula) along with some iron-nickel, magnetite, and hydrated silicate and, at a temperature of about 400° C, makes water and long chains of carbon. Ammonia, another gas in the pre-solar nebula, allows the formation of amino acids and the constituent bases of DNA and RNA. Indeed, some of the amino acids found in the human body have been detected in meteorites.

The Comet/Asteroid/Meteorite Connection

Meteorites clearly come from space, but this doesn't really tell us very much. Where is their source? Many planetary scientists believe that both comets and asteroids are a source of meteorites. Fine particles of dust litter the paths of comets, and those with Earth-crossing orbits will deliver debris to Earth in the form of Brownlee particles

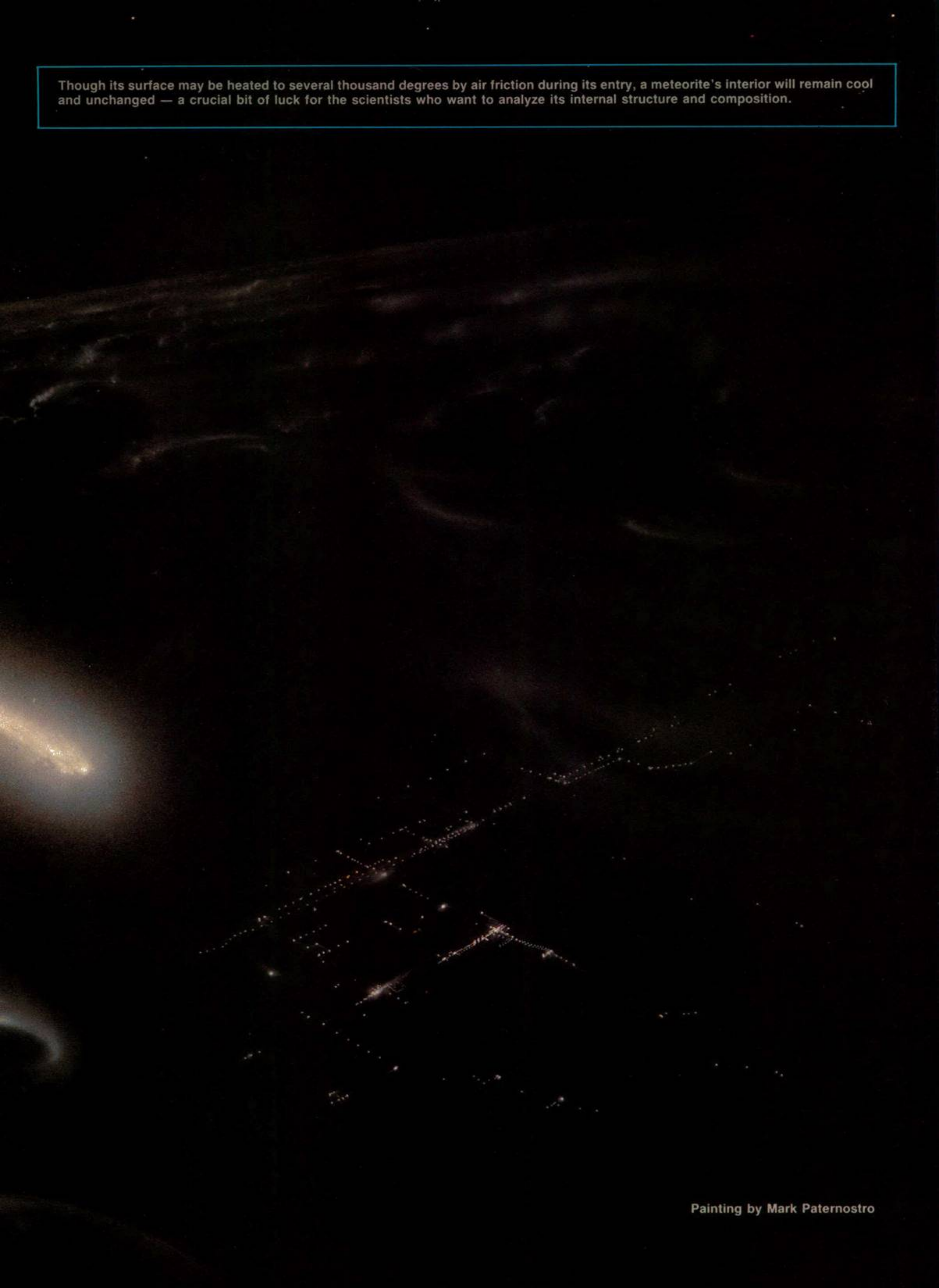


Above: Viewed with polarized light, the minerals of a meteorite stand out: feldspar is white; pyroxene is red and blue. Photo courtesy of Dr. Michael J. Drake. Below: Sliced, polished, and etched with acid, an iron meteorite displays a Widmanstaetten pattern. Photo by Ivan Dryer, courtesy of Ronald Oriti.



PATERNOSTRO ©87

Though its surface may be heated to several thousand degrees by air friction during its entry, a meteorite's interior will remain cool and unchanged — a crucial bit of luck for the scientists who want to analyze its internal structure and composition.



Painting by Mark Paternostro

This Geminid meteor was a small, fragile lump of matter probably spawned from a comet — though the Geminid parent object isn't yet known. After a brief blaze of glory, microscopic fragments of the meteor will slowly drift, perhaps for several years, through the stratosphere. Photo by Rick Schmidt.

by means of meteor showers. (For instance, the Perseid shower in August comes from Comet Swift/Tuttle.) Comets are also believed to contain carbonaceous and hydrated silicate minerals, found in chondritic meteorites.

The spectra of C-, S-, and M-type asteroids are similar to the spectra of carbonaceous, silicate, and metallic meteorites, respectively. Furthermore, the parent-body theory which accounts for different types of meteorites can account also for different types of asteroids and is a strong argument for a connection. M-type asteroids could be the exposed cores of parent bodies that have collided and fragmented and may be a source of iron meteorites. S-type asteroids may be fragmented mantles of parent bodies and a source for achondritic stone meteorites. And both comets and C-type asteroids could be a source for chondritic stone meteorites.

Additional evidence of the asteroid/meteorite connection comes from the infrared spectra of some asteroids. Vesta appears to have an infrared spectrum similar to that of a combination of pyroxene and plagioclase minerals. In fact, Vesta itself has been suggested as the eucrite parent body. Collisions with similar asteroids may have spalled material from Vesta's surface, and some of this may have arrived on Earth as meteorites. Another asteroid, Dembowska, appears to have an olivine and pyroxene mineral composition. Both asteroids might be a source for achondritic stone and stony-iron meteorites.

One problem with the idea of the asteroid belt as a meteorite source region concerns the mechanics of getting the material to Earth. One suggestion is that an asteroid could collide with another asteroid and pick up enough energy to move out of the asteroid belt and toward the Earth. But a collision of such violence is likely to melt the asteroids in question — and this clearly hasn't happened with many meteorites.

Another possible solution involves a more subtle sequence of events. Suppose that one asteroid has a near-hit with another and, as a result of the mutual perturbations, strays into one of the Kirkwood gaps. Once in the gap, the asteroid might receive enough energy from the repetitive tugs of Jupiter to be kicked out of the asteroid belt into an Earth-crossing orbit. Although the data are scant, trajectories of several meteorites have been photographed sufficiently well to determine their pre-entry orbits — which turn out to be similar to the Earth-crossing Apollo orbits.

Because they have changed relatively little over the past 4.5 billion years, comets, asteroids, and meteorites are essential to our understanding the history of our solar system. As we urge the development of spacecraft to explore the areas of the solar system that we haven't yet examined — a largely futile exercise, at present — we might take some comfort from the thought that we already have our hands on some pieces of celestial material: meteorites.

Edward J. Ciaccio is a student at Hahneman University Medical School. His last article for ASTRONOMY was "Landscapes of the Solar System," which appeared in the July 1982 issue.

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Target: Wethersfield

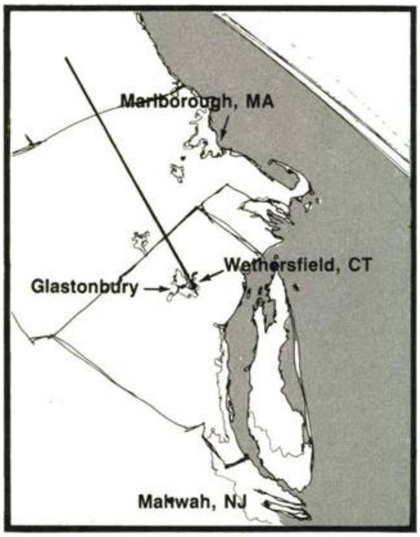
The small town of Wethersfield, Connecticut, achieved national notoriety some 11 years ago when a 349.8-gram (12.3-ounce) stony meteorite smashed through the roof of a town resident. The excitement caused by this celestial visitor gradually faded, and Wethersfield resumed its position as a Hartford suburb.

The town's dubious distinction of being a meteorite impact site was reawakened suddenly on the evening of November 8, 1982, at about 9:20 p.m. local time — only about 1.5 miles from the 1971 event. The evening was mild — in the mid 50s — and Connecticut residents were relaxing. One family was enjoying Monday night TV when a muffled explosion — "like a truck coming through the front door" — shook the household.

"It sounded like a heavy picture had fallen from its hook but much louder," Robert Donahue said. "We ran through the dining room into the living room and saw a big hole in the ceiling, then went outside and saw a hole in the roof. We then checked the upstairs closet for fire. What appeared to be smoke, dust, and fine particles of plaster filled the air and we suspected fire. We phoned the police and told them that we thought there had been an explosion."

Police immediately dispatched firemen to the residence. The meteorite was found within ten minutes of the impact by firemen. The fire marshall later reported that the object had been cool to the touch. Suspecting from the first that the object was a meteorite, the firemen requested that it be kept by the Wethersfield police until positive identification could be made.

Prior to the impact the Donahues thought they had heard noises outside. The meteorite entered the house at a 65° angle from the west-northwest. After passing through the roof and ceiling, it scarred the front door and dented the carpet and floor. Small pieces of ceiling plaster hit a parson's bench with sufficient force to gouge out several dents in the pine wood. After hitting the floor, the meteorite bounced up at an angle and impacted the dining room ceiling leaving its signature by removing more ceiling plaster. Its final descent brought it down into an old New England Hitchcock chair, damaging the seat and knocking it over. The 2.9-kilogram (6-pound) space rock then came to rest on the dining room floor.



The incoming meteor was reported by about a hundred people scattered throughout southern New England. Many calls of the sighting were relayed to David Meinke, astronomy professor at Central Connecticut State College. Some people phoned the Wethersfield family to tell about the route of the unexpected visitor.

Robert De Collibus made this report from Marlborough, Massachusetts, about 70 miles away to the east-northeast. "I was sitting in my family room watching TV when a bright light outside the window caught my eye. The object traveled in a downward path and seemed to be going down nearby," said De Collibus. "It was as bright as the Full Moon, so bright that I couldn't focus my eyes on the center of it because it was so intense. It was very white and bright, and behind it was a yellowish trail that lingered. The object fell all the way to the horizon. It was just like in the movies — your jaw dropped because you couldn't believe what you were seeing. I followed it down through the bare trees and watched it disappear over the horizon.

"It fell toward Worcester, but a bit south of Worcester. It went slowly and appeared to be moving away from me. It was so big that my first impression was that a plane had exploded," added the Marlborough resident. "It lasted for about three seconds at the most, but the trail lasted a bit longer. The object did not appear to break into pieces," said De Collibus. "I first noticed it when it was about 30° above the horizon. It was about 9:20 p.m."

About 84 miles southwest of Wethersfield, Connecticut, Ted Pace, a former Navy navigation officer, was driving in Mahwah, New Jersey.

"It was between 9:15 and 9:20 p.m. The object was streaking across the sky in an east-by-northeast direction. It was plunging down in a fiery trail, and it had a reddish-orange color with pieces coming off of it," said Pace. "I thought it fell in the Mahwah area but the atmosphere was clear, so I guessed it could have fallen a great distance away.

"It was a direct vertical fall and was

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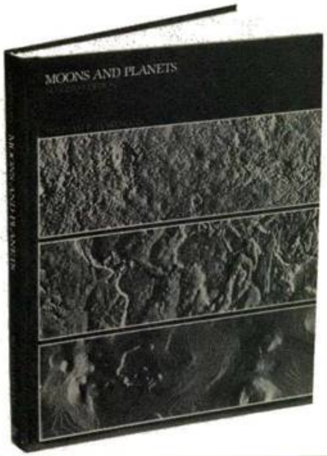

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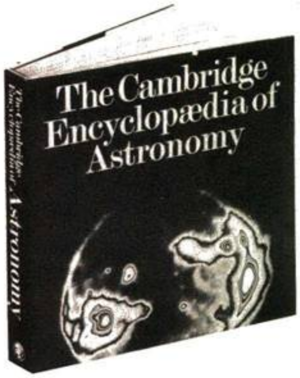

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Entrance of the cosmic visitor. Photos by author.

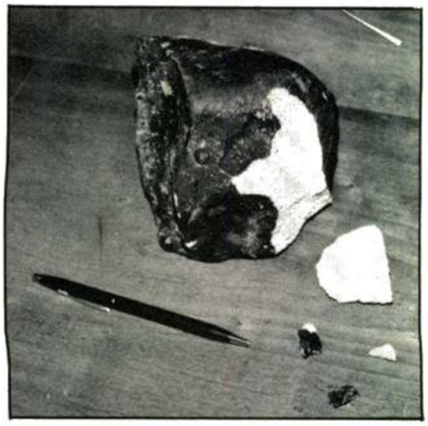
much brighter than Venus, probably brighter than the First Quarter Moon. From Mahwah it appeared to fall somewhere up the Connecticut coast and probably some distance north of White Plains, New York. I didn't hear any noises, but I was in my car at the time," he said.

In Spencer, Massachusetts, about 50 miles away, Judy Maloney reported: "I was standing at my kitchen sink at about 9:15 p.m., looking out the window to the southwest, when I saw a very large round object that looked reddish-orange and looked like a fireworks display," she said. "I then realized something was falling from the sky. I could clearly see an object on fire with flames surrounding it. It approached the ground at a 45° angle moving towards Southbridge," said Maloney. "It lasted for about two seconds and pieces or sparks flew off it in various directions. It then went behind the trees."

The most spectacular account of the incoming meteor came from Stan Hedden, a resident of Glastonbury, Connecticut, who witnessed the event just five miles away from the impact site. "It was close to 9:20 p.m. and I was jogging. I was headed straight west and saw a flash like lightning, and the entire sky was lit. I looked up, and about 5° northwest of the zenith a very white and large object about the size of a basketball appeared. I thought it was space junk and saw fragments come off the eastern rim of it," said Hedden.

"The object stayed in one position and did not move — it was a head-on look. It could easily cast shadows. Six or more pieces fell from it in varying sizes," he said. "It then disappeared, and it never moved. I kept on jogging and began counting, anticipating a sound so I could judge the distance. I counted between 30 and 50 seconds and heard a series of six or more 'rifle shots' going off in the direction of Wethersfield," added Hedden.

The Wethersfield meteorite.



Based on these and other eyewitness accounts, it appears that the meteorite that struck the Wethersfield house may have been one of several fragments that are now scattered about the central Connecticut area. The preliminary evaluation of these reports suggests that the meteorite came in from the west-northwest and that — based on measurements of the roof and ceiling holes made by Charles Hammond of Trinity College — the meteorite entered the house at a 65° angle.

Tuesday brought a deluge of media people, curiosity seekers, and scientists to the Wethersfield impact site. Roy Clarke of the Smithsonian Institution's Museum of Natural History made a preliminary identification of the meteorite as an L-6 chondrite. The object is now on loan to the Smithsonian and is currently undergoing study at Batelle Northwest Laboratories in Richland, Washington.

These events mark Wethersfield as a unique site, the target of two celestial visitors within 11 years. The search continues in central Connecticut for more pieces of this great meteorite, a cosmic nomad "captured" by a gracious Wethersfield couple.

Phil Dombrowski, an earth-science teacher and amateur astronomer, resides in Glastonbury, Connecticut, approximately five miles from the impact site.

You Can't Go Home Again

Tonight I have tried to touch my past, but the past is not there. I usually walk by the playground where I played as a kid, but tonight, for reasons known only to my neurons, I paused and wandered into it. I walked over the ground where once I had run. I stood where once I had stood with a baseball glove and expectantly awaited the next pitch. I thought of the hundreds of victories and defeats that had happened here — but found I could taste almost nothing of the pleasure or frustration they had contained. I thought of the friends who had played here with me. For a moment I saw us playing together and heard our shouts, but then I was alone in the silence and the night again, knowing that those friends were grown and scattered and we would never again share a baseball game. I was alone, that is, except for two cars, for now the playground was a parking lot. I imagined that the owners of the cars were somewhere sweeping floors and emptying wastebaskets, erasing small pieces of other people's yesterdays.

After a while I left the playground, left it to people who would see in it only a parking lot, and I headed home. But a few blocks from home I paused again, at another place where I could look into the past. This was not my past, but the past of someone named Harlow Shapley. I stood next to the site of the observatory where Shapley had first studied astronomy. I imagined young Shapley standing here and gazing through a telescope, not suspecting that the work he was beginning would eventually lead him to great discoveries about the universe. But then I was back in the present, and instead of an observatory I was seeing one of the buildings of the University of Missouri School of Journalism.

I started to leave, but then a thought struck me. I looked again at the building before me, and I realized that this was not really the site of Shapley's observatory, and that the parking lot in which I had been standing was not really the site of my playground. The work of Harlow Shapley made it possible for me to realize that the place where he had first studied astronomy and the place where I had played as a kid were really countless billions of miles away, somewhere far in space and growing farther away every second.

The year before Harlow Shapley arrived at the University of Missouri, the head of the Astronomy Department, Frederick Seares, had begun a study of variable stars. When Shapley arrived in 1907, Seares put him to work on it, not knowing that he was steering Shapley toward the key to the universe. After a few years Seares left for the new Mt. Wilson Observatory in California. Shapley went to study, first at Princeton, and then to Mt. Wilson, where Seares had

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helped arrange a job for him. Shapley again worked with Seares, and then, on his own, began studying one particular kind of variable star, the Cepheids. Shapley realized that Cepheid variables could be used to map the universe. A variable star is one whose brightness increases and decreases. Cepheid variables vary their brightness very regularly. Cepheids come in many sizes, and for every bit more massive a Cepheid is, it is also a bit brighter, and its brightness changes a bit more slowly. The largest, brightest Cepheids vary most slowly, and the smallest, dimmest Cepheids change brightness most rapidly. By observing how often the brightness of a Cepheid varied, Shapley could know how bright the Cepheid would appear if it were nearby; by comparing this with how bright it actually appeared, he could determine how far away it was. By determining the distances to large numbers of Cepheids, Shapley was able to outline the Galaxy. He discovered that the Galaxy was much larger than had been thought, and that Earth was not in the center but two-thirds of the way out. This latter finding led other astronomers to discover that we orbit around the center.

With this method Shapley could have gone on to make much greater discoveries, but he thought that our Galaxy was all there was to the universe. Another Mt. Wilson astronomer, Edwin Hubble, believed otherwise, however, and soon proved that there were galaxies beyond our own. Using Shapley's method, Hubble located some Cepheid variables in nearby galaxies and determined how far away they were. When Hubble compared the distances of galaxies with their motions, he made the most astonishing discovery of all: the farther away a galaxy was, the faster it was receding. The universe was expanding; all the galaxies were flying away from a common point.

I gazed up into the night, into the stars we sometimes mistake to be changeless, and I saw them rushing through space like grains of sand riding the winds of a hurricane. I saw myself riding on a planet that was flying around the center of the Galaxy, and I saw myself riding in a Galaxy that was flying madly away from the Big Bang. I felt my heart beating, and I realized that each heartbeat was occurring thousands of miles away from the last one. My heart beat, and I watched the point where it occurred streaking away into space as the planet left it behind. My heart beat again, and again I watched the point where it occurred receding into space. My heart beat again, and in only moments the point where it occurred was farther away than the Moon. Gazing far beyond the Moon, I saw the long trail of my heartbeats spread through space, a long trail that is my life. I saw all the places and all the actions of my life stretched out one behind the other. I saw the spot where this morning I woke up — now only empty space. I saw the spot where last week I sat and felt upon my face the warmth of the Sun — now far behind the Sun and utterly cold. I saw meals that had stretched across a million miles, and books that had kept me company for billions of miles. Somewhere far, far back I saw myself standing in a playground and throwing a baseball a thousand miles. I saw myself gradually growing smaller until I was a baby — and then was not there at all.

Surrounding the line of my life were the lines of billions of other lives, all twisted together like the threads of a massive rope, a rope that Earth lays across the universe, a rope called human history. I looked back along that rope and saw the places where other people had lived their lives. I saw where Edwin Hubble had sat at a desk and calculated how fast the universe was expanding. I saw where young Harlow Shapley had stood and gazed through a telescope, not suspecting that he was flying around the Galaxy and away from the Big Bang, but beginning the work that would reveal it. I saw where Thomas Edison had invented the light bulb, a place that now was very dark. I saw where Beethoven had conducted one of his symphonies, a place now utterly silent. I saw where Magellan had stood at the bow of his ship and looked down into the churning waters of the Pacific Ocean, a place now utterly still. I saw where the Roman legions had won fierce battles, but there were no monuments marking those battlefields. I saw where a Greek philosopher had wondered whether it just might be possible that Earth was not the fixed center of the universe. I saw the vast distance over which humans had built Stonehenge. I saw where humans had huddled inside caves and gazed out into the darkness. And far beyond that I saw where some vaguely human creatures had wandered across African savannas.

Then I looked beyond human history and saw the history of Earth stretched through space in a long helix. As Earth circles the center of the Galaxy, the path it traces through space weaves back and forth. I looked along this helix and saw some tinier helixes gradually changing; I saw the life of Earth flowing from one shape into another. As I looked farther and farther back I saw the dinosaurs shrinking into small reptiles, which turned into fish and slithered back into the sea. I saw plants growing smaller and simpler and withdrawing from the land until it was empty. I saw fish growing smaller and simpler until they were no longer fish but tiny creatures riding in the waters. I saw these creatures losing more and more of their cells, growing cruder until they fell apart into molecules. I looked into the ages before life and saw where rain had pounded the land and turned into rivers and oceans, and where volcanoes had poured lava over the land and gases into the sky. I saw where meteors had bombarded the newborn planet, and then I saw the planet forming out of a dense, swarming cloud of gas and dust.

I stood there a while and looked back along the path Earth had traced across the universe, a path stretching a third of the way back to where the Big Bang occurred. I looked at all the places of my life, places now unreachably far away and growing farther every moment. I watched all the places of human history receding into the darkness. I watched the entire history of the planet receding and receding and receding.

Then I turned and started walking, walking on pavement I sometimes mistook to be steady but which now felt ever falling, walking on a giant bullet that was flying through space, flying from a gun called the Big Bang. I turned and headed — no, not home, not to a place I returned to again and again, not to a place where much of my past had been lived, not to a place where each day I added a little more life to all I had lived there before, for no person on Earth and no being in the universe has such a home. We are all homeless; we are all cosmic refugees forever wandering, lugging with us little scraps of our past. I headed not home, but merely to the apartment where I do most of my wandering.

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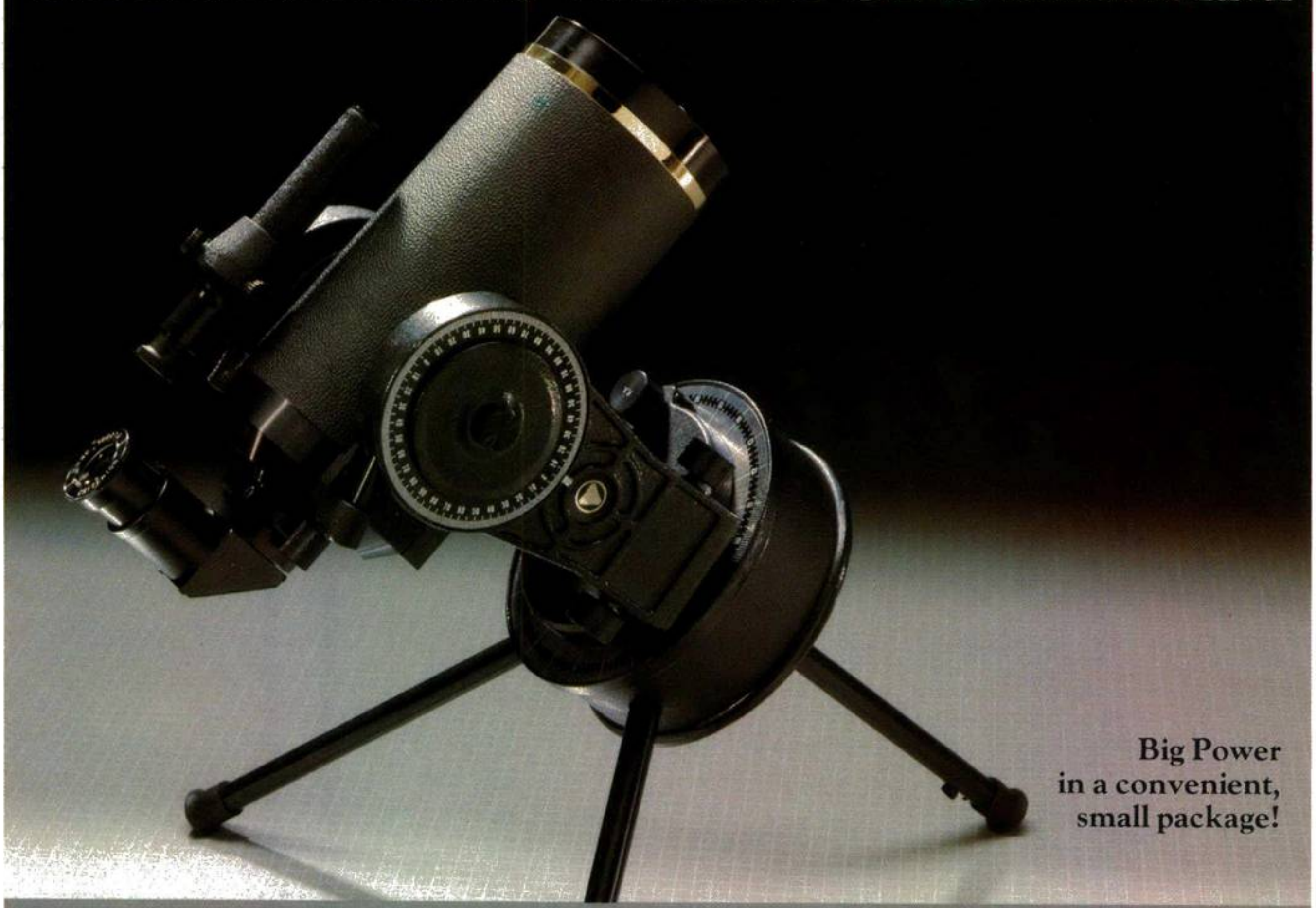

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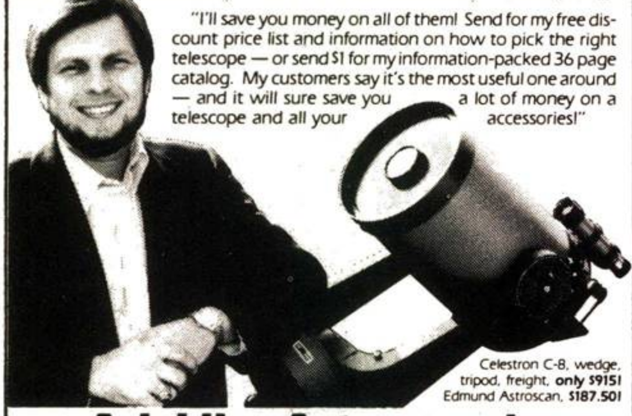

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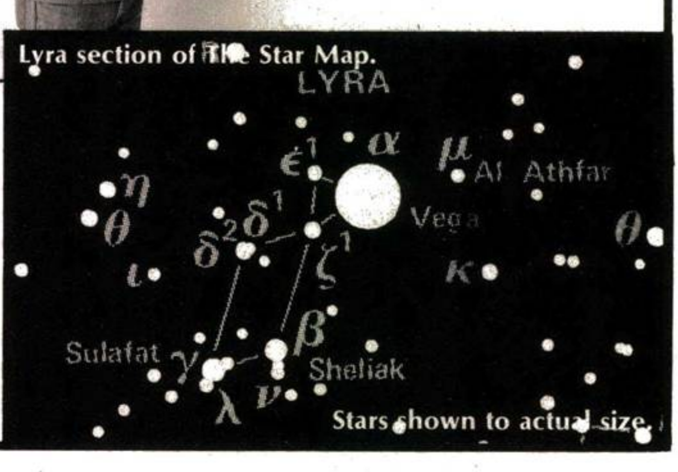
Lyra section of The Star Map.



Stars shown to actual size.

ASTRONOMY
IN FOCUS

Eggs-actly the Right Advice

Sir / It was with considerable amusement that I read Ken Fulton's article in the March ASTRONOMY. Amusement because not very long ago I may well have been included in his rogues' gallery of frustrated and angry observers.

Though astronomy has been a lifelong pursuit of mine, it was not until several years ago that I finally bought a telescope, my first, a little twopointfour. Since I really didn't know what to expect, the views I saw took my breath away. Wow! — I would gasp — look at those equatorial bands on Jupiter, and the rings around Saturn! I'm actually seeing this stuff with my own eyes!

Well, the observing bug bit hard, and I was hooked. Soon enough, "aperture fever" hit and I began scrimping and saving for an 8-inch Schmidt-Cassegrain. After a long wait it finally arrived.

As I set it up that first night, I was practically trembling with anticipation. Jupiter was instantly zeroed in on. Then: Omigod! What kind of lemon has been palmed off on me? My dismay was boundless. Night after night of observing paid off with nothing but nearly blank sketches.

Convinced the scope was at fault, I wrote the company and performed every test on it known to man. When the tests seemed to show that the scope was optically excellent, I just about gave up observing once and for all.

Then, by purest chance, I happened to be discussing the problem at a party where a professional artist overheard my heartfelt moaning and offered some advice that, at the time, seemed bizarre. Learn to draw an egg, she said. Keep observing and in the meantime draw eggs. And keep on drawing eggs until you have done one that actually *looks* like an egg. She explained that observing your subject was as difficult as drawing it and that to observe correctly, you must look into your subject and through it with a perfectly relaxed mind. Then you'll detect subtle nuances and details that escape ordinary scrutiny.

Well, draw eggs I did. I drew eggs by the score until they actually began to look like what they were meant to be. Not entirely coincidentally, I began to see, equally slowly, more and more planetary detail. Since then, I have learned a good deal about seeing and transparency and eye fatigue, but still, whenever I hear a novice astronomer deride his fine new scope, my best advice is — draw an egg!

Thanks again for the article.

Pete Scott
Indiana, PA

Spirals or Ellipticals

Sir / A small question of detail has arisen that I hope you can clarify. In "To Sculpt The Galaxies" (January '83), author Francis Reddy states that spirals constitute 75 percent of all known galaxies. Frank Shu, in *The Physical Universe*, corroborates this. In fact, on page 293 he claims that the figure is 70 percent.

However, Edward Harrison in *Cosmology* (p. 55) says the majority (60 percent) of all galaxies are elliptical. William Kaufmann in *Black Holes and Warped Spacetime* (p. 137) states that "spirals and barred spirals account for only a third of all galaxies. Ellipticals are clearly the majority."

Who's winning this race?

Steve Doriss
Fort Bragg, CA

— Most galaxies are ellipticals. However, since ellipticals contain very little interstellar gas for the production of new stars, low-mass ellipticals are very red and very faint — in short, they are difficult to detect. The great number of these low-mass systems became clear in the past 15 years with the advent of sufficiently sensitive detectors. On the other hand, spirals really do make up about 75 percent of all bright (easily detectable) galaxies.

Which Remnant?

Sir / On page 8 of the January 1983 issue of ASTRONOMY, in the article "To Sculpt the Galaxies" by Francis Reddy, you printed a picture of a supernova remnant. Which object is this? What constellation is it in?

Edwin E. Barnes
Seattle, WA

— The remnant is known as S 147, and lies on the Taurus-Auriga border near the galactic equator. S 147 is more than 3° in diameter and is probably around 50,000 years old.

Which Hassan Do You Mean?

Sir / One of our patrons asked us to find the source for the following quotation, which appeared in the February 1983 ASTRONOMY on page 22:

> *Unknowingly, we plow the*
> *dust of stars blown about us*
> *by the wind, and drink the*
> *universe in a glass of rain.*
> Ihab Hassan

We have no way of knowing which of the many Hassans may have penned that line. If you or any of your readers could tell us the source of the quotation, our patron would be most grateful.

Jay P. Smith
Irvington Library
41825 Blacow Road
Fremont, CA 94538-3395

Poetical Lunar Eclipses

Sir / The December 30th total lunar

eclipse prompted me to reread Ben Jonson's beautiful poem about the Moon, "Hymn to Cynthia," from his play *Cynthia's Revels*. I encountered the following lines:

> *Earth, let not thy envious shade*
> *Dare itself to interpose;*
> *Cynthia's shining orb was made*
> *Heav'n to clear, when day did*
> *close. . .*

This seems to be a description of a lunar eclipse, with the shadow of the Earth falling on the Moon. Do the readers know of any other examples of lunar eclipses mentioned in poetry?

John Lockwood
Washington, DC

40-Inch Not the Largest Scope?

Sir / I was particularly interested to see the splendid and, in several cases, unusual views of the Yerkes 40-inch in your December issue. That telescope is a monument to the scientific and engineering skill of our predecessors. It is beyond debate that the Yerkes telescope is not only the largest refractor now existing, but that it has done more for astronomy than any other instrument of its type.

However, without wishing to tarnish the acclaim so richly deserved by the 40-inch and those associated with it, I feel it is time the historical record is put straight. Contrary to the statements made in the article, the Yerkes telescope is not — by a considerable margin — the largest refractor ever completed. As is well attested by contemporary accounts of authorities such as E.M. Antoniadi, Sir Norman Lockyer, and Sir David Hill, there was erected in Paris (for the Exhibition of 1900) a refractor of 49.2 inches' aperture. There is no question that this telescope was fully operational and was, indeed, used by Antoniadi for at least a year.

The final demise of this instrument, recorded rather sketchily in later works, was brought on by an entirely non-astronomical factor: lack of funds — a problem from which Yerkes was somewhat protected. The fundamental flaw in the Paris project, it seems, was that it was *entirely* supported by private finance.

J. C. Taylor
Oxford, England

Charles T. Yerkes

Sir / In reference to your article on Yerkes Observatory, you and your readers may be interested to know that Charles Tyson Yerkes was involved in the development of the London Underground system between 1900 and 1905. Although his methods made him unpopular at the time, he provided an effective foundation for the London Underground group.

W. Wooller
Surrey, England

Galileo and Sunspots

Sir / Douglas Hall's article "Starspots" (February 1983) contains the assertion that Galileo was forced by the inquisition to renounce his results on sunspots. This is untrue. The charge against Galileo dealt with various points, chiefly his open support of Copernicanism. His work on sunspots was not mentioned in the charge. The Church had taken no position on this esoteric astronomical issue, so no doctrine on the subject could have been the source of official displeasure.

It is true, however, that Galileo supported Copernicanism in his *Dialogue on the Two Chief World Systems* by means of certain arguments drawn from the observation of sunspots. Galileo also had a long-standing feud with Christopher Scheiner, an important Jesuit scientist, over the question of priority of discovery. Both had done important early work on sunspots. Galileo was the first to argue persuasively, against Scheiner's planetoid hypothesis, that the spots were on (or very near) the solar surface. There is some reason to think that Scheiner's animosity toward Galileo may have played a role in the instigation of charges.

David K. Hill
Augustana College
Rock Island, IL

behind the scenes

a super opportunity

Just as this issue was ready to go to press, Paul Maley called with information that will be of interest to many observers, especially those living in south and central Texas. On the night of May 28-29, just a few minutes before midnight, the asteroid Pallas will occult the 4.8 magnitude star 1 Vulpeculae (19h 16m, +21° 23', epoch 2000.0). For those on the midline of the occultation path, the star will appear to drop to 9.6 magnitude — an event you could hardly miss.

An event like this can yield valuable information about the exact size and shape of Pallas — but only if several hundred observers stationed in the path of occultation measure the exact moments the occultation begins and ends. The asteroid's shadow will cross the southern U.S. at roughly 670 miles per hour and will be approximately 330 miles wide. At present, the predicted path crosses Texas from Dallas to Corpus Christi.

The minimum requirements for participating are: 1) you must be able to identify the star 1 Vulpeculae; 2) you must have a telescope or tripod-mounted binoculars; 3) you must be able to receive WWV time signals or calibrate a quartz digital watch via signals over a special telephone line; 4) you must own or be able to borrow a portable tape recorder to record the event plus time markers.

We'd also recommend a good star atlas. Practice finding the star before the event so that you can find it if weather conditions turn out less than perfect. By the way, WWV is your national time station — if you've never heard it, tune in at 5, 10, or 15 MHz with a shortwave radio receiver.

Interested? Mr. Maley will send any Texan a "Pallas Observer's Guide" if you send a 9" x 12" self-addressed stamped envelope (with 54 cents postage on it) to the following address:

Mr. Paul Maley
15807 Brookvilla
Houston, TX 77059.

This guide explains the techniques you'll need to carry out the timing. If you decide to participate, you'll be assigned to a specific location in the "fence" of observers that will span the occultation path.

If you live outside Texas, you may still want to observe 1 Vulpeculae as Pallas approaches and passes it. Reports may be sent to:

International Occultation
Timing Association
P.O. Box 596
Tinley Park, IL 60477.

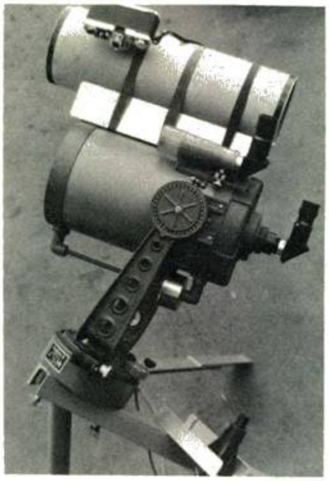
Incidentally, the National Bureau of Standards will broadcast a 45-second update on the occulation path for ten days preceding the occultation at four minutes past each hour. These updates will be voice transmission — you just tune in to hear them.

Sincerely,

Richard Berry

Richard Berry
Editor

INTRODUCING THE SIDE SADDLE MOUNT for the CELESTRON COMET CATCHER



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photographing the giant planets

photography in astronomy

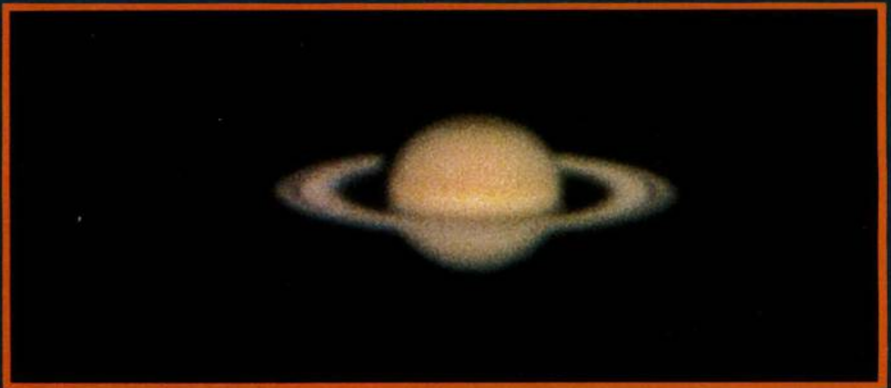
Saturn reached opposition on April 21st, and Jupiter reaches it on May 27th — so now is an excellent time to gear up your telescope and camera for a photographic survey of these two planets. (See also Gazer's Gazette on page 51, this issue.)

Let's quickly go over what's involved in getting a good photograph of Jupiter or Saturn. Fact #1 is that both planets are fairly small objects: Jupiter's equatorial diameter is currently about 45″ of arc, and Saturn's rings spread about as far, 42″. This basic fact has a few important consequences. The first is that you need high magnifications to get a decent-sized image on film. High magnifications, in turn, call for long, photographically slow f/ratios. This all sounds pretty gloomy, but Fact #2 helps you out a lot: both planets are relatively bright.

Rigging the Camera

To get the long focal lengths that provide high magnification, you are faced with two courses of action. The first seems the simplest: use a telescope that has a whopping big focal length. But to get an image of Jupiter, say, that measures 10 millimeters across on film, you'd need a focal length of nearly 46,000 mm or some 150 feet! Since there's no commercially made telescope that comes even close to this, the only other course open to you is to take the image delivered by your optical system and enlarge it to get the same effect.

There are two ways of enlarging the image, the *afocal* and the *eyepiece projection* methods. In the afocal system, you position a camera with an ordinary photographic lens so that it looks directly into the eyepiece of the telescope. Here's the procedure: take the camera lens, focus it to infinity, and open the aperture diaphragm to the fullest. Then train the scope on the object and focus it by eye, using a medium-power eyepiece. Take the photo by placing the camera so that the lens points straight into the eyepiece while you sight through the camera's viewfinder. When you get it all lined up, trip the shutter.



In December 1977 when Saturn's rings were moderately open, Ernest Wright took this photo with a 12½-inch Maksutov, eyepiece projection to f/30, and a 2½-second exposure on High-Speed Ektachrome (160 ASA).

If you plan to do a lot of afocal photography, you'll want to construct a wood or metal frame that rides on the telescope tube and holds the camera in place. But to start with, you can put the camera on a separate tripod and maneuver it to look into the scope's eyepiece. (This won't always be easy!)

The chief advantage of the afocal method is that you can use any scope and any camera — there's nothing extra to buy. Its big disadvantage, however, is awkwardness.

Eyepiece projection — which is something of a misnomer, since the afocal system clearly uses eyepiece projection also — has become the preferred choice of most lunar and planetary astrophotographers. It works by coupling your camera body to the telescope's focuser with an adapter that holds an eyepiece inside itself. These adapters sell for $20 to $30, depending on your camera body and telescope. Check the ads of the telescope and accessory manufacturers.

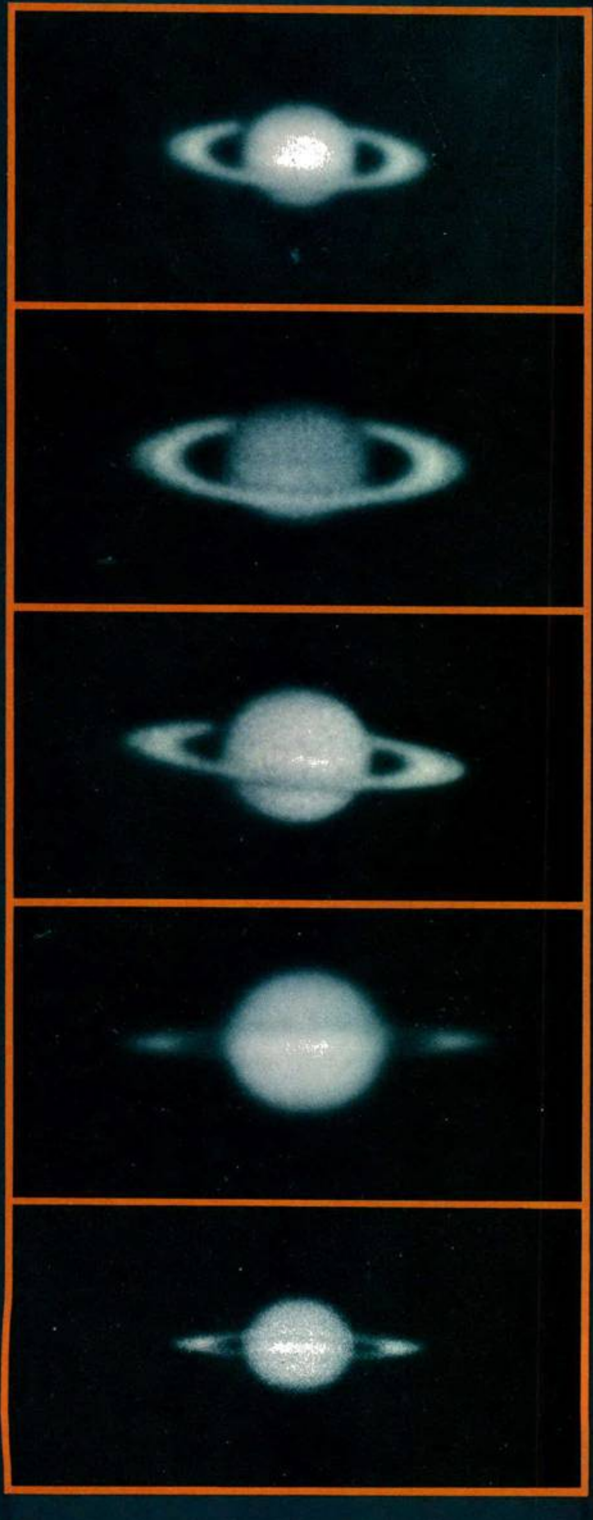
The procedure for using an adapter is as follows: insert a low, medium, or high-power eyepiece into the barrel of the adapter and lock it in place. Then attach the adapter to the camera body. Next aim the scope at the object and insert the camera and adapter into the eyepiece focuser. You then peer into the camera's viewfinder, wiggle the scope a bit to center the object, focus, and finally trip off the shutter to make the exposure.

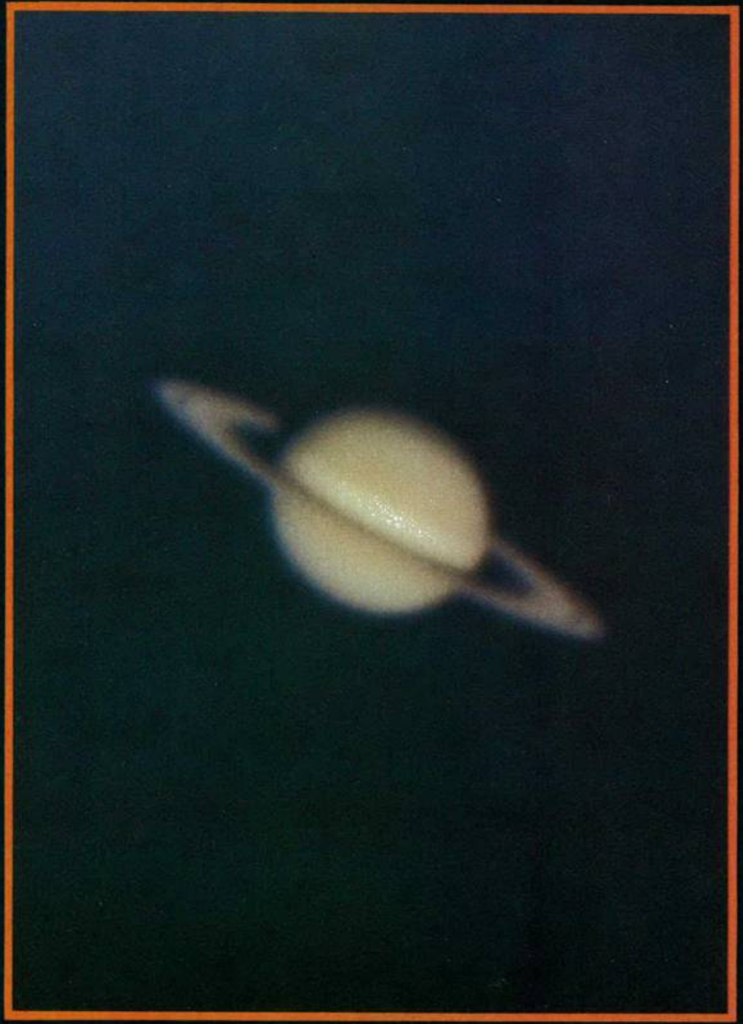
Getting the Right Exposure

Determining the right exposure to use is a simple matter of working though the "exposure equation": $E = f^2 / S \times B$. Translated, this says that the exposure (E) in seconds equals the square of the system's focal ratio (f) divided by the film's ASA speed (S) times a brightness index (B). This seems pretty straightforward: film speed you know, and Jupiter has a B value of 40 and Saturn's is 10. The only snag lies in determining the total focal length — a figure you need to work out the effective f/ratio of the system.

With an afocal rig, proceed as follows: divide the camera lens focal length by the eyepiece focal length. The result is a magnification factor, which you multiply the original scope's f/ratio by to get the effective focal ratio. For example, suppose you have a 50 mm camera lens and a 12.7 mm eyepiece on an f/8 scope. Thus, 50 / 12.7 = 3.94, and 3.94 × 8 = an effective focal ratio of f/32.

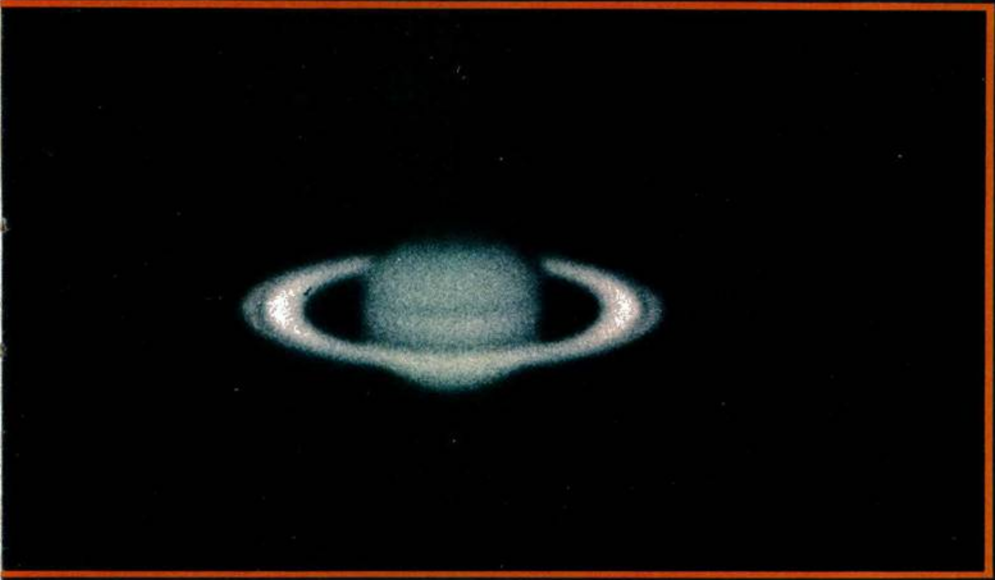
With eyepiece projection set-ups, it's a little more complicated. Calculating the magnification factor calls for you to measure the distance from the center of the eyepiece when it is placed in the adapter to the film plane in the camera body. (You may have to check your owner's manual to see how to tell where the film plane is.) Take this distance and divide it by the eyepiece focal length — remember to use the same units — and subtract 1 to get the magnification factor. For instance, let's say you have a 9 mm eyepiece and the distance from its center to the film plane is 58 mm. Work out the magnification in this way: 58 / 9 = 6.44, and 6.44 − 1 = 5.44, which is your magnification factor. If the telescope has a focal ratio of f/10, the effective focal ratio

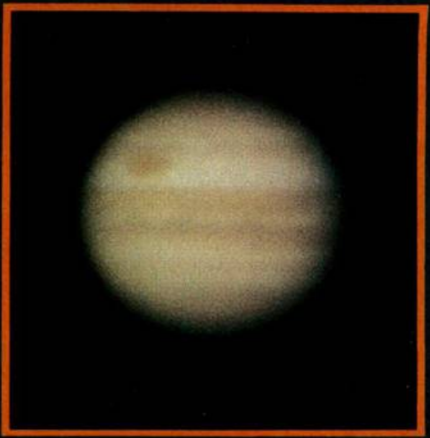




Left: Lester Yuill's sequence shows the changing tilt angle of Saturn's rings from December 1976 (top) to March 1979 (bottom).

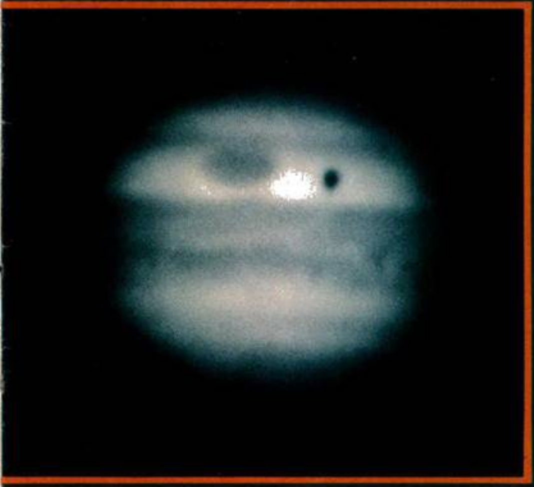
Above: photo by Charles Capen. Below: E. Ken Owen's photo was taken with Tri-X and a 4-second exposure at f/185, using a 10-inch reflector in February 1976.



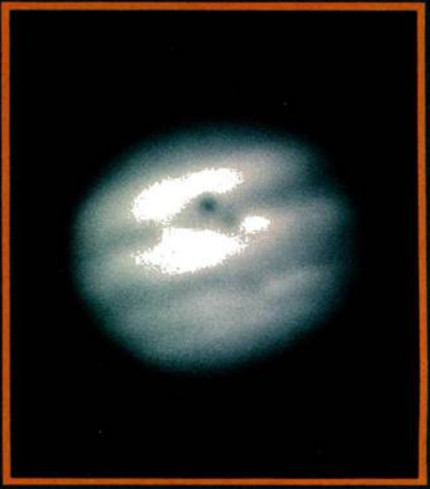


Above: This Jupiter photo was taken by James Rouse with a 5 second exposure at f/105 on High-Speed Ektachrome with an 8-inch Newtonian.

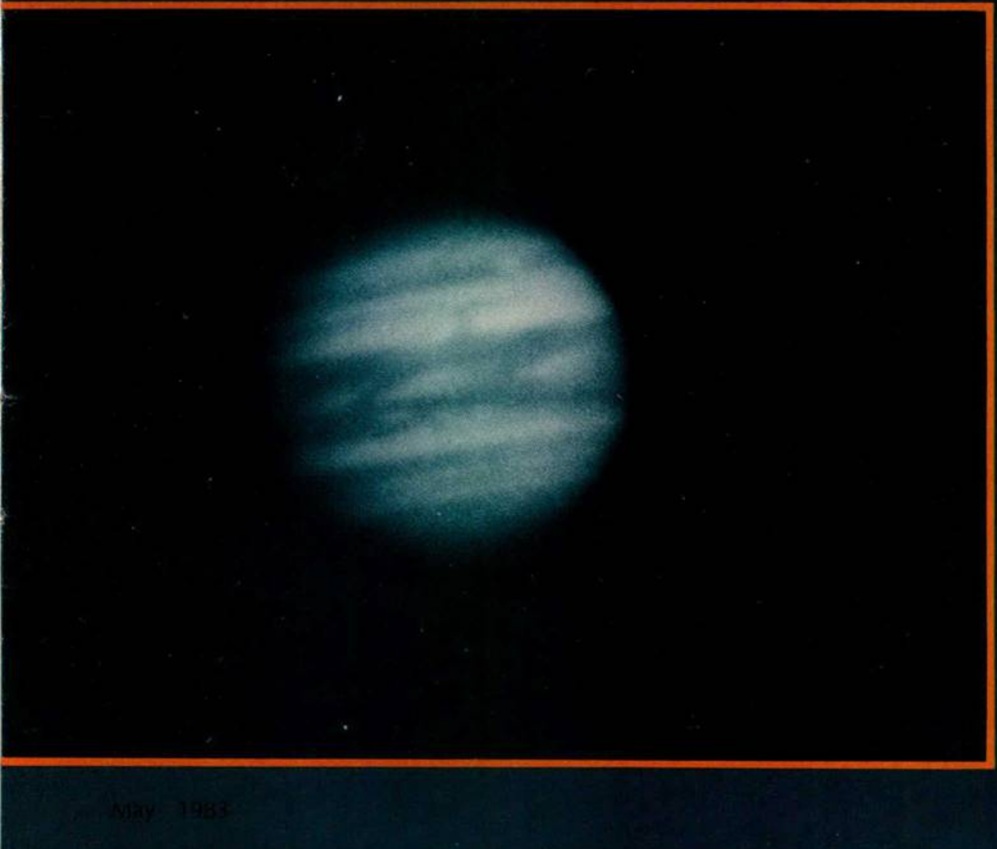
Above: Thomas Rotkiewicz used eyepiece projection with his 12.5-inch Cassegrain to take this photo in February 1977. His effective focal ratio was f/104 and the exposure (through a medium blue filter) was 3 seconds on Tri-X.



Left: James Rouse's photo of Jupiter caught the shadow of Ganymede on the disk. The telescope was an 8-inch Newtonian and the exposure (at f/105) was 4 seconds on Kodak SO-410 film.



Right: Leonard Marek's Jupiter shot was taken with an 8-inch scope, eyepiece projection to f/195, and a 2-second exposure on Tri-X.

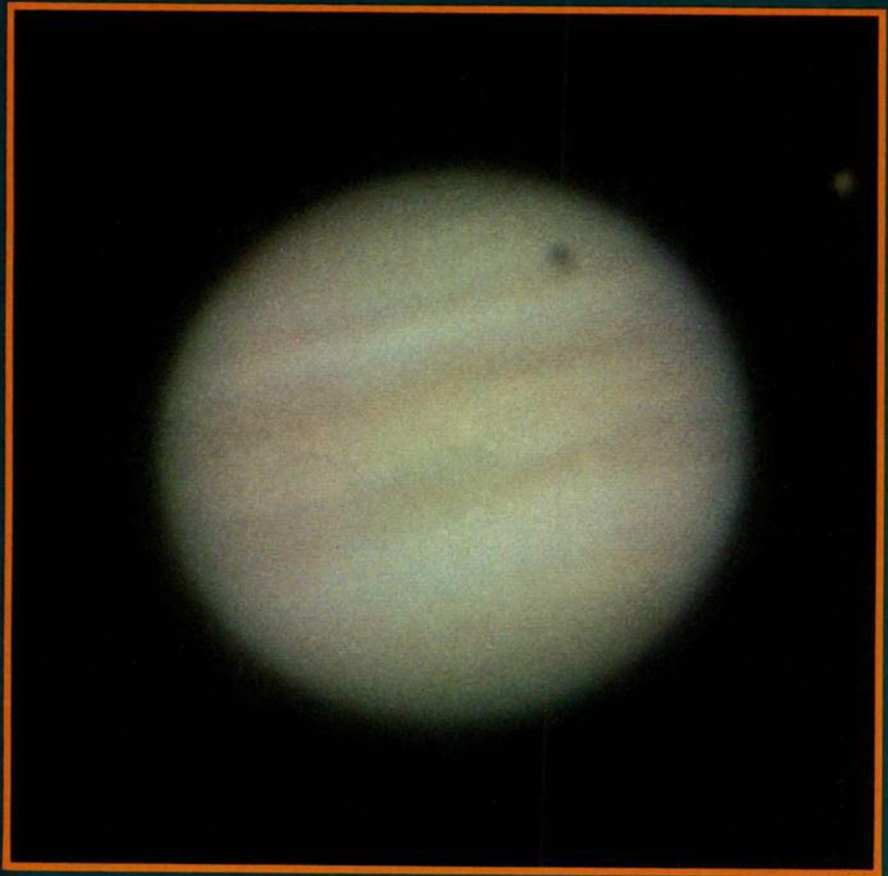


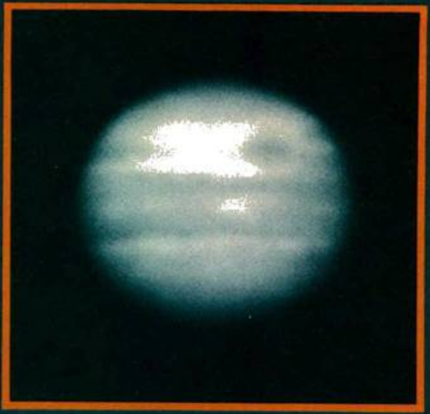
Below: Ron Price's photo was a 6 second exposure at f/150 on Plus-X using a 12-inch Cassegrain scope.

is then f/54.

Let's now run through a calculation to show how the exposure formula works. Suppose you want to photograph Saturn on Ektachrome 400 with the eyepiece projection arrangement we just worked out. The value of S is 400, B is 10, and f is 54. Performing the arithmetic, we get 54 × 54 = 2916, 400 × 10 = 4000, and 2916 / 4000 = 0.729 second. Since there isn't any such shutter speed on a camera, you round it off and give Saturn a full 1-second exposure.

The exposure formula is an excellent guide, but a little experience soon teaches you that there is no one "best" exposure for astronomical objects. Accordingly, when you've worked through the exposure formula, take its result as a middle value and give the object at least two stops greater and lesser exposure. In this case, try ¼ and ½ second as well as 2 and 4 seconds. You'll discover that a good exposure for the center of the disk is undertimed for the limb regions and one that reveals a crisp edge to the planet washes out the center. To your eye, it all looks about the same, but film tends to exaggerate differences in apparent





Left: Craig McCaw's photograph of Jupiter and two of its satellite's shadows was taken with a 16-inch reflector, Kodachrome 64, and a 1 second exposure. Above: Al Ernst used a 24-inch Cassegrain scope, Kodak 2415 film, and a 2 second exposure at f/120 to take this Jupiter shot.

brightness across the disk as compared with visual observations. Hence the rule — bracket your shots.

What's the Best Film?

In choosing film for your camera, you should opt for the fastest available, because keeping the exposure short (to minimize bad-seeing effects) is all-important. You could choose a faster, low-magnification system with a slower and less-grainy film, enlarging the image in the darkroom, but experience shows that doing the enlargement *in the optical system* works better. This means you are going to be using slow f/ratios that will push you toward fast, somewhat grainy films — such as Ektachrome or Fujichrome 400 and Kodacolor or Fujicolor 400. (If you feel adventurous, try Kodak's new Kodacolor VR-1000 color negative film.) For black and white, use Kodak Technical Pan 2415 — which has the happy advantage of being both reasonably fast and having little grain.

For those who have their own darkroom, black and white will probably give the most satisfactory results, at least to start with. It costs less, and you can fiddle around with the negative to get a good print yourself — two good factors that encourage experimenting. With Jupiter, for instance, the limb regions are much fainter than the center of the disk. In making a print, you can take a negative that was exposed for the limb (making the center of the image too dense) and expose the paper correctly for the limb. Then, using your hands or a small hole cut in a sheet of black cardboard, you can apply extra exposure to the center of Jupiter's disk to "burn in" the belts. The result will be a stunning photo that captures a lot of the visual impression you get at the eyepiece.

Unfortunately, very few commercial photofinishers know how to get a good print from a typical astronomical negative: they tend to give you washed-out Saturns floating in a muddy sky — terrible! If you have all your processing done commercially, you'll do best to work in color and to choose slides over prints for the candid reason that they are harder to botch. And because slides give you less chance to manipulate the image after exposure, you'll do well to increase the bracketing range an additional stop up and down from the "ideal."

Don't Forget the Telescope!

Like all astrophotography, good results in planetary picture-taking depend on every part of your system working perfectly. So be methodical — gather all your photo equipment before you go outside, calculate ahead of time the exposures for the eyepieces you intend to use, check to see if you have a cable release, and so on. Make sure your scope is ready, too. Since exposures can run as long as several seconds, a clock-driven equatorial mounting in good working order is a must. (An undriven Dobsonian will suffice, but only when you juggle the components so as to come out with an exposure time of ¼ second or less.) Check the mounting's polar alignment; it doesn't have to be as precise as deep-sky astrophotography requires, but it ought to be close.

Next, go over the scope with a critical eye looking for loose fittings — clamp rings, counterweights, finderscope, tripod legs, etc. — and tighten them. If the camera-adapter sleeve slides around too freely in the focuser drawtube (check it with the camera attached), a little tape on the sleeve will make it fit more snugly.

A last problem area: the SLR camera is a great instrument, but it has one bad defect for astrophotographers. When the mirror flips out of the optical path, it can jiggle the entire scope for several seconds, ruining the definition in the photo. Therefore, after you have focused the picture, lock the mirror up and *then* release the shutter.

But with some cameras, this approach isn't really convenient, because you are forced to waste a frame in the process. The remedy for this is the ancient and honorable "hat trick": set the camera's shutter to B or T and click the shutter open while a hat or sheet of black cardboard is covering (but not touching) the end of the telescope tube. After waiting a few seconds to let the shimmy die out, flick the cardboard aside to make the exposure. With a little practice you'll be able to make exposures of one-half second or longer surprisingly consistently.

If you've never tried high-magnification planetary photography, the list of do's and don'ts looks pretty formidable — but they're really only common-sense solutions applied to the problem. Start off with black and white film, and don't be discouraged if the results of the first few rolls wind up in the trash can. Keep at it — you'll soon be cranking out magnificent photographic records of Jupiter's and Saturn's appearance this year. *Robert Burnham.*

ASTRONOMY
REVIEWS

Clusters of Galaxies
(Webb Society Handbook, vol. 5)
Kenneth Glyn Jones, ed.
241 pages, paperback, $16.95
Enslow Publishers (1982)

Many backyard observers have heard of the great Coma Berenices cluster of galaxies and have seen photos of it taken with big professional telescopes. But if you were to ask the average amateur telescope owner to point out where it is, or whether he has seen it through his scope, you'd probably get a blank look or a negative reply. Because so much work has been done on the cluster by the professionals — and because so little information is generally available about it — most observers assume you need large pro-size scopes to detect it. This notion is mistaken.

While it *is* true that you need a large scope if you want to study the cluster in detail, today's amateur astronomer, using the newly popular "light buckets" of 14 to 20-inch aperture, can expect to see several members of this cluster of galaxies — and the Coma cluster is just one of a great many in the sky.

The recent boom in large telescopes has brought about a change in amateur astronomy and deep-sky observing in particular: a new class of celestial objects has been brought within reach — and this provides the rationale behind the new volume in the Webb Society Handbook series. The book compiles information that has not been readily available to non-professionals — information culled from expensive reference books usually housed in the libraries of observatories, universities, and planetariums.

Clusters of Galaxies continues the high standards set by the preceding four volumes. It combines observations from amateur and professional astronomers — though its emphasis, naturally, is on the amateurs. The verbal descriptions are interesting and informative, and are based on observations made using both large and small telescopes. They're useful in helping you to identify a particular galaxy in your own scope. (Some of the observations were made with scopes as small as 8½ inches in aperture, which tells you how accessible these clusters are.) The book also provides excellent finder charts that show the immediate vicinity of the cluster — a great aid at the telescope.

The section on clusters of galaxies forms one part of the work; there are two other sections as well. One focuses on the Virgo area, while the other is on "poor" galaxy clusters — those that have only a few members but are still within the range of backyard observers' equipment. For anyone who owns a large scope, the entire book will be of great use. Anyone with a smaller scope will find it less useful, but he will still be able to work with the section on Virgo and observe some of the objects in the main roster of clusters.

There are some mistakes, but they appear to be limited to typographical errors, such as an incorrect coordinate here and there. Any observer who uses this book along with a good star atlas should have no difficulty in spotting the goofs.

If you are a diehard deep-sky observer, you will treasure this volume. I suggest that you keep the book near the telescope, where it will do the most good. The Webb Society is to be congratulated on a fine addition to their Handbook series — and I heartily recommend the other four books, too. *Ronald J. Morales.*

The Realm of the Nebulae
Edwin Hubble
207 pages, hardcover, $30; paperback, $8.95
Yale University Press (1982)

In 1889 the small town of Marshfield, Missouri (pop. 2,961) was the birthplace of a scientific giant who even today remains fairly little known — Edwin Hubble. After uneventful early years, Hubble pursued a law degree, made something of a name for himself as an amateur boxer, and eventually prepared for his life's work by earning a graduate degree in astronomy from the University of Chicago.

Hubble's lifetime (1889-1953) spanned the Spanish-American and Korean wars. His scientific contemporaries included Harlow Shapley, Albert Einstein, Henrietta Leavitt, George Hale, and Walter Baade. Fittingly, it was during his lifetime that three of the world's great telescopes saw "first light": the 40-inch Yerkes refractor, the 100-inch Mt. Wilson instrument, and the 200-inch glass giant of Palomar.

During Hubble's youth, the faint smudges in the night sky now known to be distant galaxies were thought to be gaseous regions located within our own Milky Way Galaxy. They were collectively referred to as "nebulae" and divided into green nebulae and white nebulae — the latter being what we today call galaxies. Later, in an effort to clarify the terminology, Hubble wrote, "The term *nebulae* offers the values of tradition; the term *galaxies* the glamour of romance."

At the age of 30, Edwin Hubble joined the prestigious Mt. Wilson Observatory staff. Shortly after arriving, he began taking lengthy exposures of white nebulae, concentrating on the Andromeda Spiral Nebula. Before 1920 it wasn't known with certainty that other galaxies such as our own existed, although this had been guessed and hinted at. However, when Henrietta Leavitt and Harlow Shapley discovered and refined the relationship between period and luminosity of Cepheid variable stars within our Galaxy, it was the stimulus Hubble needed to announce that Cepheids were also present in the Andromeda Spiral Nebula — an announcement that opened wide the door to extragalactic astronomy. His efforts with the 100-inch telescope had succeeded in resolving the outermost portions of the Andromeda Spiral into a vast celestial whirlpool of extremely faint individual stars.

In 1924, after carefully checking his calculations and results, he shared his epochal discovery with the world. Those faint, misty patches in the sky were actually colossal star-cities located far beyond our own Galaxy — remote and alone at distances that previously were only the subject of conjecture. Nor was this all: subsequently, Hubble announced that the velocities of recession of galaxies are directly related to their relative distances. These two profound statements — that galaxies do exist, and that they are moving away from each other (and us) at stupendous speeds — revitalized astronomy and prompted a surge of interest in astrophysics. Certainly, few cosmological discoveries had such impact as did Hubble's.

During his productive years Hubble had found that spectra of remote galaxies were redshifted to varying degrees. From the amount of redshift he was able to determine the velocity of galaxies, and by connecting velocity to distance, he derived the relation now known as Hubble's Law. The work still not complete, Hubble continued to study his nebulae, entranced by their mystery and remoteness. As he did so, another idea took shape in his mind. After examining hundreds of photographs of galaxies, he worked out a classification scheme according to their shape and apparent structure.

In 1935 Hubble gathered together his major findings and synthesized them into a series of popular lectures delivered at Yale University. These lectures, a distillation of his work of the preceding decade and a half, were published in 1936 as *The Realm of the Nebulae*, a book that was meant, in the author's words, to ". . . furnish an authentic picture of a typical case of scientific research in the process of development."

Far surpassing his intent, his work stands as a key building-block on which future discoveries will rest.

Now reprinted again by the original publisher after a period when Dover had it in their reprint list, the book commences with an introduction that describes the basic methods of astronomical research, the language of astronomy, and the nature of the all-important Cepheid variable stars. The eight succeeding chapters discuss historical research on galaxies and Hubble's scheme of galaxy classification. About the latter, he wrote, "Order has emerged from apparent confusion and the planning of further research is greatly simplified."

The book delves into the distribution and distances of galaxies, examines the Local Group of galaxies, and concludes with a summary of the subject.

The Realm of the Nebulae is not just a rehash of facts and figures; rather it is a cogent statement by the man who discovered, formulated, and articulated theories upon which much of modern cosmology rests. And though it was written nearly half a century ago, the presentation remains fresh, logical, and surprisingly up-to-date. Readers will find its contents to be intelligible, meaningful, historically accurate, and thoroughly delightful reading. *Gail O. Clark.*

The Galactic Center

G. R. Riegler and R. D. Blandford, eds.
216 pages, hardcover, $30.25
American Institute of Physics (1982)

About 30,000 light-years away from us lies the center of the Milky Way. Although shrouded by vast clouds of dust, the galactic center is gradually yielding its secrets to the probing eyes of infrared, radio, and high-energy astronomy. All of the data from these different regions of the electromagnetic spectrum suggest that our Galaxy contains a massive black hole in its midst. This book is a collection of research papers delivered at the California Institute of Technology in January 1982.

High Energy Astrophysics

M. S. Longair
412 pages, hardcover, $49.95; paperback, $19.95
Cambridge University Press (1981)

High Energy Astrophysics is an introductory text intended for students of

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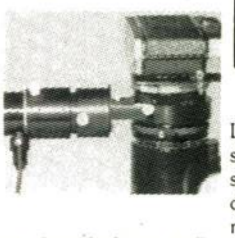

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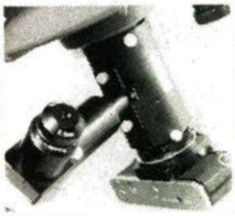

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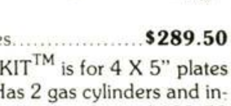

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physics and astronomy — Longair develops all of the necessary physics from elementary physical principles. The text concentrates on one specific problem — the origin of cosmic rays — and introduces high-energy astrophysics and astronomy in the course of examining this problem. The story of cosmic ray detection, how these particles reach the Earth, and how matter in the Universe is accelerated to relativistic speeds is told in the context of solving a scientific puzzle.

Weather and Climate on Planets
K. Y. Kondratyev and G. E. Hunt
755 pages, hardcover, $95
Pergamon Press (1982)

Intended for the professional scientist, this book covers a lot: from terrestrial atmospheric phenomena to those of Venus, Mars, and Jupiter. It includes a great many references to already published literature, as befits a review volume.

Astronomy: From the Earth to the Universe, 2nd ed.
Jay M. Pasachoff
550 pages, paperback, no price given
Saunders (1982)

This is a general introduction to astronomy for students taking a college level course that avoids most of the mathematics. It is generously illustrated in black and white and has sections of color plates.

Comet Predictions for 1984
C. Townsend, J. Rogers, S. Hannsen
30 pages, looseleaf, $4
Published by the authors (1983)
[order from: 3521 San Juan Ave.,
Oxnard, CA 93033]

This publication provides coordinates and other information, such as magnitude and distance from Earth and Sun, for six short-period comets that will be observable during 1984.

Amateur Radio Astronomer's Handbook
John Potter Shields
119 pages, paperback, $14.95
Phoenix Electronics (1982)
[order from: 1334 W. Arndale,
Stow, OH 44224]

Shields provides his reader with a survey of radio astronomy and atmospheric constraints on observing; then discusses types of radio instruments (both antennas and receivers) in general, before describing how to build them. An appendix lists addresses of manufacturers and has a parts list.

Computers for Sea and Sky
Stephen J. Rogowski
105 pages, paperback, $9.95
Creative Computing (1982)

This book is "a compendium of computer programs and algorithms for use in aviation, navigation, astronomy, surveying, meteorology and sailing." The astronomical routines compute altitude/azimuth conversions, the date of Easter, time measure into arc measure, days between dates (and day of the week), day of the year, sunrise and set, Julian date, and time zones. The book's programs are in "generic" BASIC.

Yale Bright Star Catalogue, 4th ed.
Dorrit Hoffleit
472 pages, paperback, $35 (+ $2 domestic postage)
Yale University Observatory (1983)
[order from: P.O. Box 6666,
New Haven, CT 06511]

This handy catalog compiles basic data on 9,096 stars. It provides 1900 and 2000 coordinates; photoelectrically determined V, B-V, U-B, and R-I magnitudes; and rotational velocities. There are MK spectral types and radial velocities for 93% of the entries. It also lists star names (Bayer's Greek letters, Flamsteed's numbers, and common names).

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eye on the sky

jupiter and uranus meet in scorpius

by Fred Schaaf

the wanderers

This month offers excellent opportunities to observe the planets: the second of three 1983 conjunctions between Jupiter and Uranus occurs on May 16; and Saturn, Venus, Mercury, and the Eta Aquarid meteor shower are all visible at some point during the month.

Early in May, the constellation Scorpius rises in the southeast several hours after sunset, and yellow-white **Jupiter** hangs 5½° north of first-magnitude Antares. The planet is now backtracking along nearly the same path it took in the first three months of the year. In retrograding, it passes Antares and other stars in the area for the second of three times in 1983. What is most interesting, however, is that Jupiter is again traveling past not only fixed stars, but also another, much slower planet.

Uranus, at magnitude 5.8, is the most distant planet visible to the naked eye. The second of three close passages this year between Jupiter and Uranus takes place on May 16. The much brighter Jupiter (magnitude −2.1) is 50′ north of Uranus; the two lie almost exactly between the fourth-magnitude stars Psi (ψ) and Rho (ϱ) Ophiuchi, on the verge of crossing the border into Scorpius. This separation is virtually the same as it was during the two planets' first conjunction in February; they will be about twice as close at their final encounter in another four months.

Although the two planets will still be at a relatively large elongation from the Sun in that early autumn encounter, they will not be as bright as they are in May. Nor will they be visible all night long, as they are toward the end of this month, when both of them reach opposition just 27 hours apart.

In North America, **Jupiter** is at opposition on the afternoon of May 27, and Uranus on the evening of May 28. This follows the same-day oppositions of Mars and Jupiter in 1980 and Jupiter and Saturn in 1981, as well as the oppositions of Mars and Saturn in 1982 that were only 10 days apart. So the rare concentration of outer planets that is occurring in this part of the 20th century continues to cause conjunctions and paired oppositions — remember the bridge of all the planets at once spanning the sky on those February mornings of last year? Some of the best congregations of planets are yet to come, as we will see in early 1984.

For information on viewing the Moon, planets, and deep sky objects with telescopes, see **The Backyard Astronomer**.

With a pair of braced or tripod-mounted binoculars, try comparing Jupiter's Galilean satellites with Uranus. The outermost of the four moons, Callisto, ought to be nearly the same as Uranus in magnitude and about five times closer to Jupiter when at greatest elongation. The best time to make such observations will not be right around opposition, when the Moon is also at opposition (Full phase), but rather near mid-month — when the planets are distinctly closer together, too. When nearest to Earth on the 28th and 29th, blue-green Uranus will be over four times farther away than Jupiter, whose globe appears almost three times wider than Uranus.

Another gas giant in the evening sky is **Saturn**, which is well placed in the southeast by dusk. Since it was at opposition on April 21, it is still bright and easily observable. This month Saturn's magnitude fades from about +0.4 to +0.6, while its slowing retrograde motion brings it to within about 7° of slightly fainter Spica to its southwest.

For over three hours after sunset, **Venus** will be the dominant source of light in the sky. Although its greatest elongation is next month, for most of us Venus is actually a little higher in May. It is, moreover, visible for a longer time after the end of twilight. Our sister planet brightens to magnitude −3.8 during May and can be compared with Jupiter — at its brightest for the year — when the two are at similar altitude in the west and east, respectively. The altitude of Venus is 38° at sunset on May 11 — quite high, though not as good as it will be in the superb morning apparition this autumn.

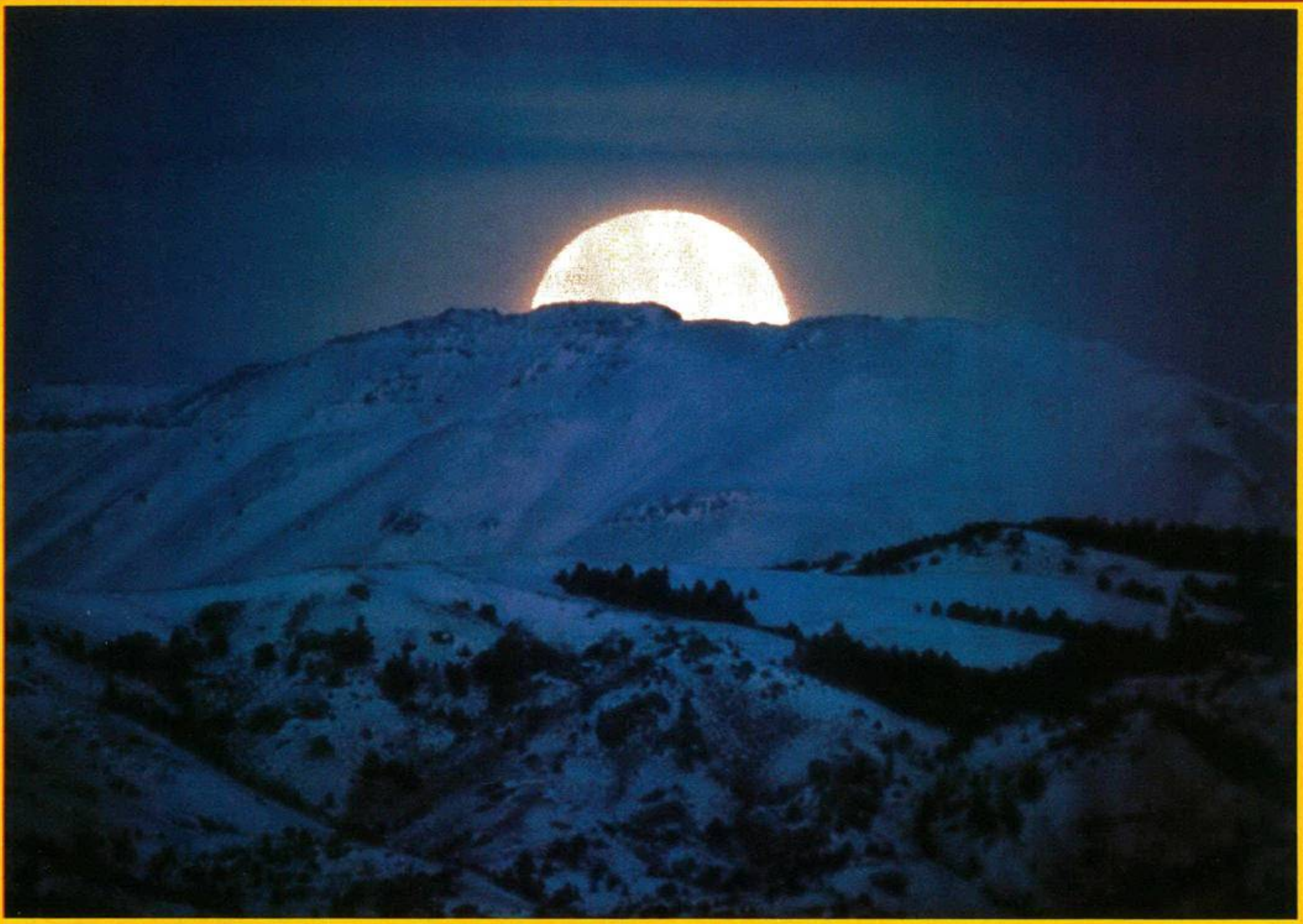
Viewers with binoculars can find the 4.9 magnitude star 139 Tauri no more than ¼° north of Venus on the evening of May 8; on the evening of May 30, Pollux is very noticeable just 4° north of the planet — note Procyon also in line to the south. Venus' most spectacular conjunction, however, will be the one visible on the evening of the 15th in North America. That night the crescent Moon will pass only 1½° below Venus.

The situation of the other inner planet this month is quite different. **Mercury** is at inferior conjunction on May 12 when it passes 0.32° south of the center of the Sun's disk — not far from the edge of the Sun. That is so close that Mercury will be only 0.0039% lit, at a dim third magnitude. It should be possible to glimpse Mercury low in the predawn sky at month's end, but during the first days of the month try to spot it above the horizon after sunset when it is a second-magnitude object.

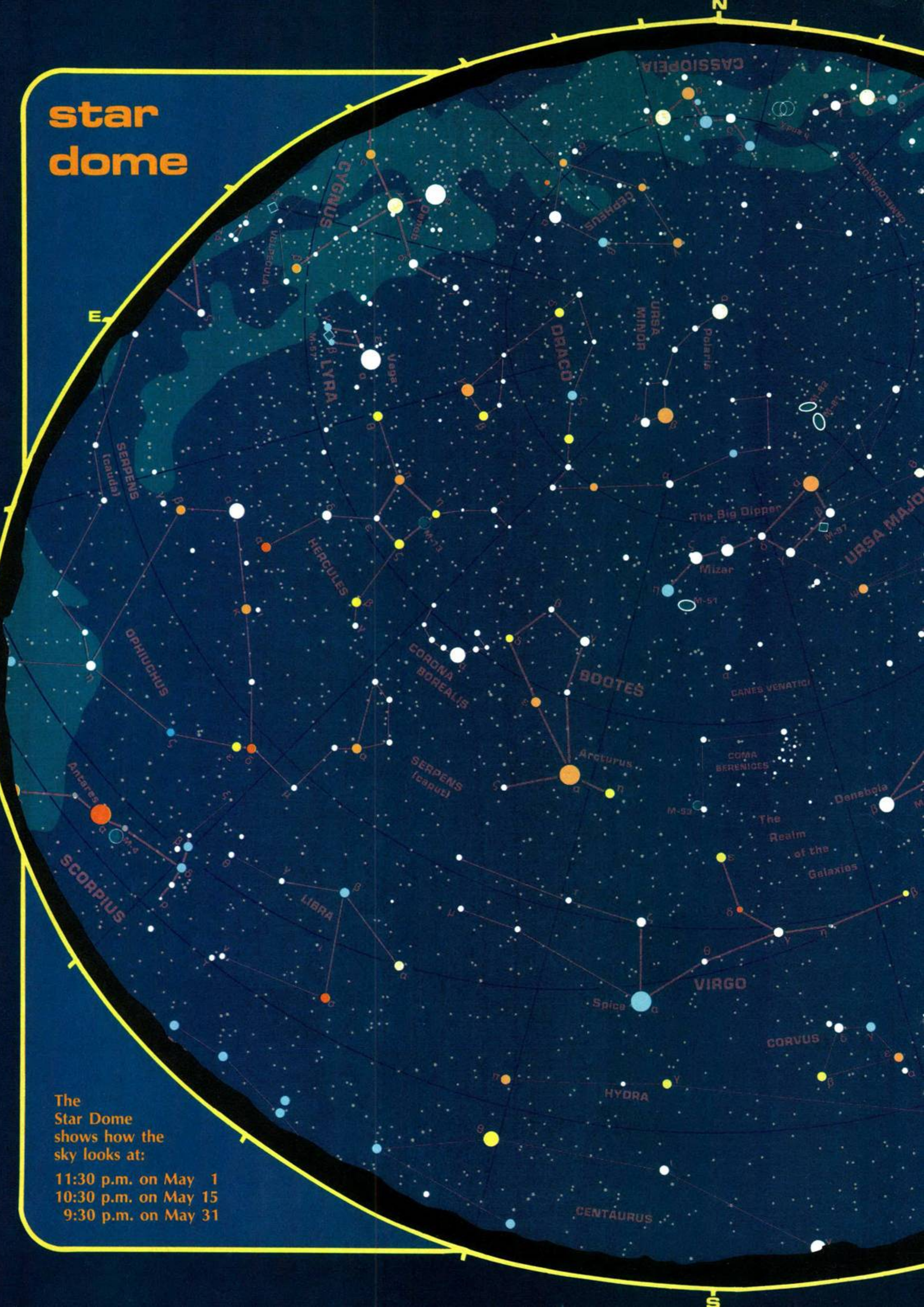
If Mercury actually passed in front of the Sun's disk, the event would be termed a *transit*. The last transits of Mercury were in 1970 and 1973; the next will be on November 13, 1986.

Would it be possible to observe a transit of the Earth across the Sun from another planet? The most interesting transit of Earth might be from Mars, which is lingering far too close to the Sun to be visible this month. As May ends, **Mars** is on the verge of superior conjunction. When it reaches that position next month, it will provide us with a good chance to examine the

Top: Dewey Vanderhoff captured this image of last December's lunar eclipse as the penumbral Moon set over Cody, Wyoming. Bottom: Observing from nearly the same site, Mack Frost recorded a similar view of the setting penumbral Moon using a telephoto lens and high-speed emulsion.



star dome


N
E
S
CASSIOPEIA
CAMELOPARDALIS
CEPHEUS
CYGNUS
Deneb
VULPECULA
LYRA
Vega
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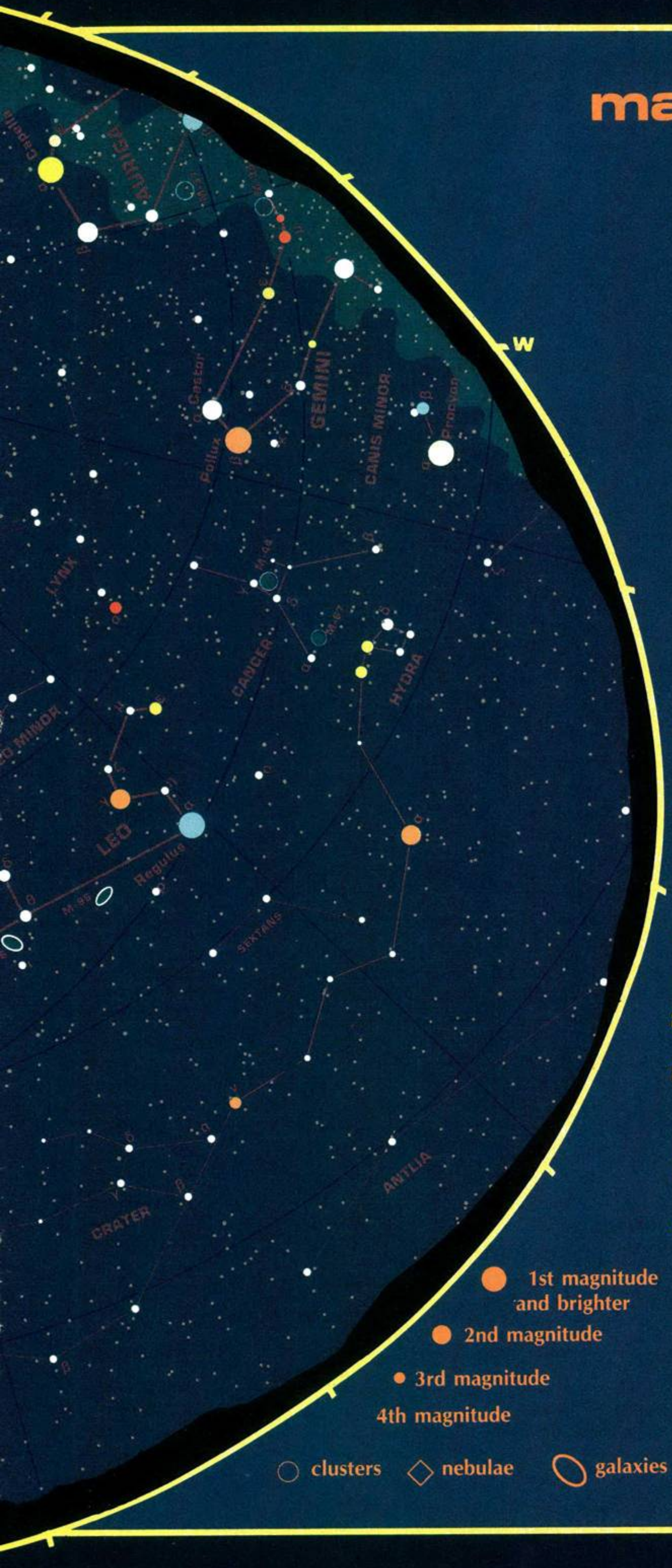
DRACO
URSA MINOR
Polaris
M-82
M-81
M-13
HERCULES
SERPENS (cauda)
OPHIUCHUS
The Big Dipper
URSA MAJOR
M-97
Mizar
M-51
CORONA BOREALIS
BOOTES
CANES VENATICI
COMA BERENICES
Arcturus
SERPENS (caput)
M-53
Denebola
The Realm of the Galaxies
Antares
M-4
SCORPIUS
LIBRA
VIRGO
Spica
CORVUS
HYDRA
CENTAURUS

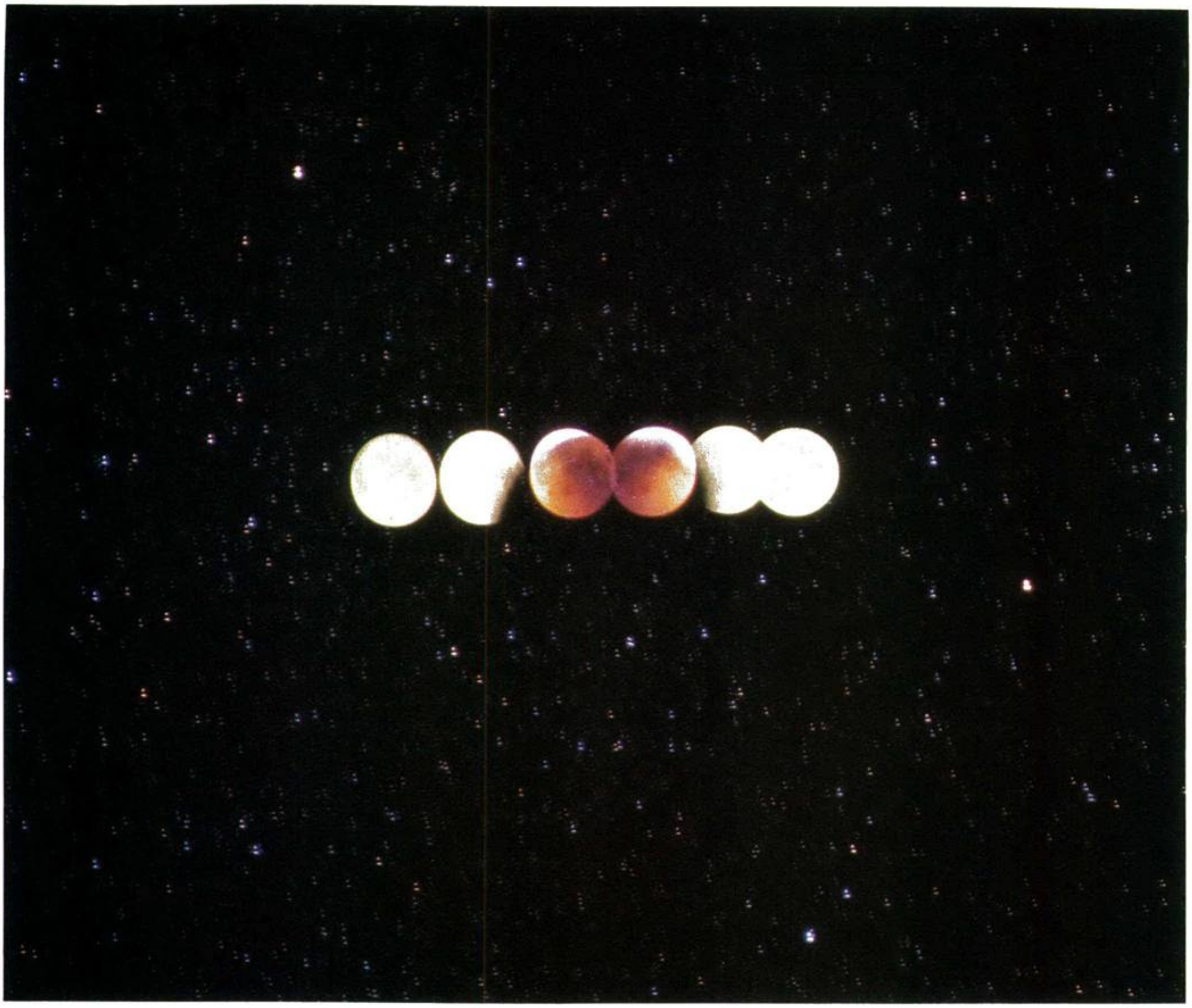
The Star Dome shows how the sky looks at:

11:30 p.m. on May 1
10:30 p.m. on May 15
9:30 p.m. on May 31


AURIGA
Capella
Castor
Pollux
GEMINI
CANIS MINOR
Procyon
W
LYNX
M44
M67
CANCER
HYDRA
LEO
Regulus
SEXTANS
ANTLIA
CRATER
1st magnitude and brighter
2nd magnitude
3rd magnitude
4th magnitude
clusters
nebulae
galaxies

may sky almanac

1st	Mercury will be briefly visible right after sunset, very low in the west-northwestern sky. You have only the next day or two to spot it before it gets too close to the Sun to be seen.
4th	The Moon is at apogee this morning: 251,136 miles. It reaches Last Quarter at 11:43 p.m. EDT.
5th	In the predawn hours this morning, the Eta Aquarid meteors will reach their peak activity. The Last Quarter Moon will greatly diminish the number of meteors you see — so expect only about a dozen per hour coming from the center of Aquarius.
8th	Venus passes a few minutes of arc south of the star 139 Tauri (see text).
12th	Mercury passes through inferior conjunction with the Sun. The Moon is New at 3:25 p.m. EDT.
15th	Tonight, the Moon will lie just to the south of Venus, and Jupiter will pass less than a degree north of Uranus (see text). The Moon is at perigee this noon: 228,365 miles.
19th	The Moon is at First Quarter at 10:17 a.m. EDT.
21st	Mercury is at aphelion.
23rd	The Moon passes about 2° north of Saturn in Virgo.
26th	The Moon will overtake both Jupiter and Uranus, passing less than a degree north of Jupiter. Full Moon occurs at 2:48 p.m. EDT.
27th	Jupiter is at opposition and visible all night long.
29th	Uranus is at opposition and visible all night long.



question of transits of Earth.

One final solar system sight deserves mention. On the morning of May 5 the **Eta Aquarid** meteors, shooting out of the southeast, reach their peak in the few hours before dawn. These meteors and the Orionids of October are derived from Comet Halley, and ought to be watched for possible changes for the next few years. Unfortunately, this year a Last Quarter Moon will seriously hamper attempts to see the few dozen hourly Eta Aquarids that might otherwise be spotted.

the starry sky

The handle of the Big Dipper now points southeast from its position high in the northern sky. The bend in this handle is marked by the most famous of naked-eye double stars, the pair **Mizar** and **Alcor**. (Mizar itself is a fine double in small telescopes.) The Big Dipper lies at about equal distances from Taurus, now setting with Venus on his horns, and Scorpius, now rising with Jupiter over his back. But the most interesting constellations at this time of year lie south of the high Dipper handle and along the curve we can extend from that handle.

South of the Big Dipper's handle and about overhead for many of us are several small, dim, yet intriguing constellations. **Canes Venatici**, the Hunting Dogs, features the stars **Cor Caroli** and **Chara**. But the most interesting object in this constellation (through which Comet Austin passed last year) is certainly **M-51**, the Whirlpool Galaxy. In dark skies, M-51 can be glimpsed with good binoculars. A telescope is needed to view almost all of the many galaxies in the constellation just to the south, **Coma Berenices** (Berenice's Hair). If you have no optical aid, but dark skies, you can get an enchanting view of **Mel 111**, the large Coma star cluster, which appears rather artistically disheveled as its members twinkle on a clear night.

West from Coma Berenices is the long bright figure of **Leo** the Lion, with **Regulus** leading and second-magnitude **Denebola** marking the lion's rear. But even these stars are no match for the one that really dominates the spring skies. If partly hidden behind trees or buildings, the star **Arcturus** can be found by extending the curve of the Big Dipper's handle about one more Big Dipper length. If there are no obstructions, you should not need any guidance to identify this magnificent object.

Facing page: Exposing at 1-hour intervals, Jerry Schad produced this multiple image of the eclipse using his 200mm f/2.8 lens and 400 ASA film. He opened the shutter for 2 seconds when the Moon was full, and 100 seconds during mid-eclipse. Right: Mickey Stewart made this pen-and-ink drawing with his 10-inch reflector.

Arcturus is a distinctly orange, magnitude −0.1 star in a rather dim region of the heavens. Perhaps no star but fainter **Fomalhaut** (in an even more deserted autumn area) stands out in such lone splendor. The kite-like form of the constellation **Bootes**, the Herdsman, is often overlooked in light of this brilliant and peculiar star.

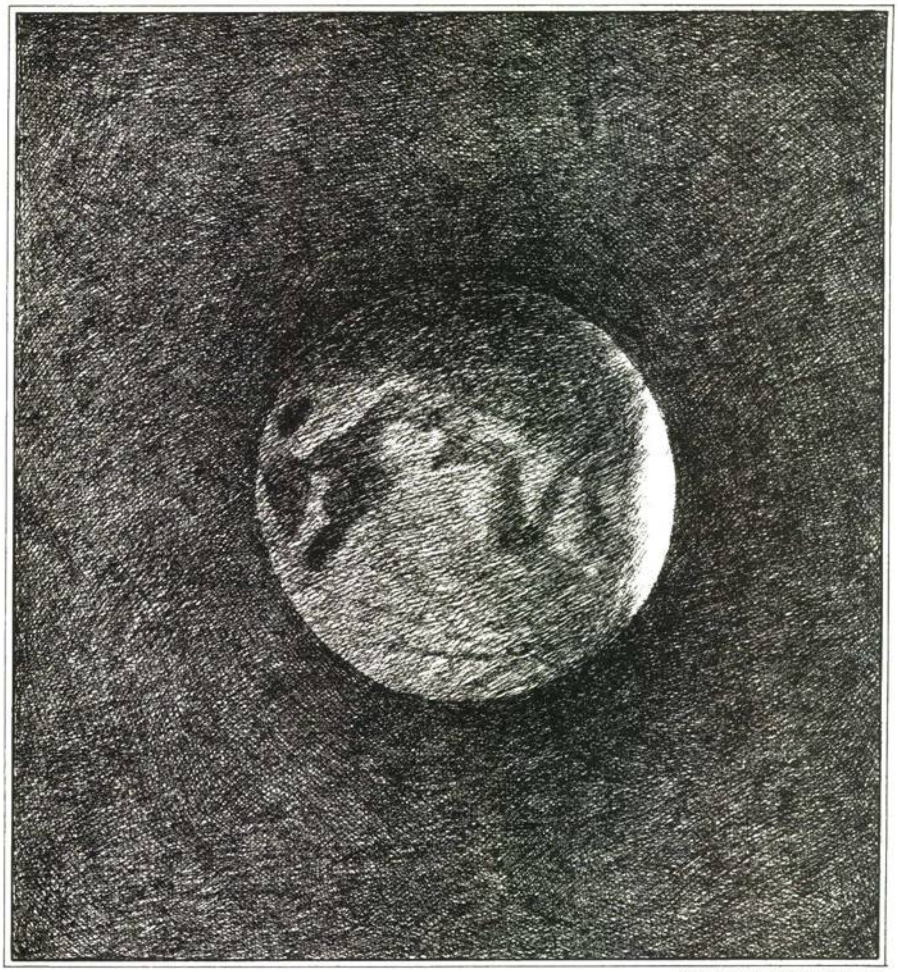
The only other comparably bright star of spring is **Spica**, which lies about one more Big Dipper length along a curve extended from the "arc to Arcturus." Spica is only a few degrees south of the ecliptic and for the past few years has had the companionship of the similarly bright

Saturn. The rest of its constellation, **Virgo** the Virgin, is certainly dim, but holds some unexpected enjoyment for observers. For instance, this longest constellation of the zodiac includes the autumnal equinox (it lies right under Virgo's reclining head). In terms of area, it is the second largest of all constellations, exceeded only — and just barely — by nearby Hydra.

Completing our tour of spring skies are **Corvus** the Crow and **Crater** the Cup. They lie south of Virgo's head and are in turn bordered to the south by **Hydra** the Water-serpent. Crater is faint, but Corvus is fairly bright and compact enough to be quite conspicuous.

skylore

The word *Corvus* is Latin for raven or crow. Legend has it that these are wise birds, and present-day experts believe that the crow family as a whole is indeed very intelligent. Members of the family are found everywhere but Antarctica, New Zealand, and a few other islands and include crows, ravens, jays, magpies, rooks, jackdaws, choughs and nutcrackers. Ravens are the largest passerine (perching) birds and the largest-bodied songbirds. Such are some of the fascinating facts about crows and their cousins. But the lore about these birds connected with the constellation Corvus is richer than we might guess.



Drawing by Mickey Stewart

In classical times Corvus was considered part of a larger constellation that also contained Hydra and Crater, so naturally the three were linked in legend. One myth tells that a crow was sent by Apollo to fetch water in a cup but tarried to eat some luscious figs instead. The crow brought back a snake, lying to Apollo that the serpent had caused the delay. But the god, of course, saw through the deception and placed all three — cup, crow and snake — in the stars, where the snake forever guards the water from the eternally thirsty crow. Readers of Aesop's fables will remember a very different story in which a clever crow dropped pebbles into a cup with a low water level until the water rose high enough for him to reach.

Another tale of Apollo's punishment of the raven relates that one of these birds brought news about the infidelity of Apollo's lover, Coronis, to the god. Whether the bird did this as a just service or simply as malicious gossip is not certain, but Apollo's penalty is known: he turned the raven's silver plumage to black. Yet Apollo also revered the raven, or at least its form, for he assumed that form at various times — most notably in the battle of the gods and giants.

The crow was also said to be a sacred servant of Athena. It is told that the bird was originally a maiden called Coronis, daughter of Coroneus of Phocia, whom the goddess transformed to save from Poseidon's desire. At first the bird was white, but she later angered Athena, who therefore turned her black.

Crows and ravens certainly have bad reputations as birds of ill omen — long before Poe. The Jobeses say that Lepus the Hare detests the raven's croak and always sets soon after Corvus rises. The early Greek Aratos described Corvus perched on a coil of Hydra, pecking the monster serpent in the age-old battle of bird and snake. Corvus may have been one of the monster ravens accompanying Tiamat, the Mesopotamian she-serpent, spirit of the chaotic sea.

There is the unsavory reference to Noah's release of a raven from the Ark before he sent out the dove that was eventually successful in bringing back a token from dry land. The raven did not come back and — it is often implied — fed on the carrion floating on the waters. In later times (several hundred years ago) Corvus became associated with Noah's raven and thus was part of a vast family of related constellations. It included the old constellation Argo (now split into three constellations) as Noah's Ark, Columba the Dove, Corvus, Hydra (the dead snake that the raven fed on), Centaurus (Noah himself, say the Jobeses), and Ara (the altar of Noah's sacrifice of thanksgiving after reaching dry land). The Milky Way was the smoke billowing up from the altar.

If we entertain this scheme, it joins the official autumn constellations of the water (or Celestial Sea) to form an almost complete circuit of "water constellations" around the southern heavens. The only major breaks are caused by the constellation Norma and by Corona Australis/Sagittarius.

Not all stellar crows have been Corvus, of course. One Australian aborigine people has Canopus as its raven — they say he fled with the most important and now lost Pleiad maiden. Conversely, the stars of Corvus have also represented many other forms. The Arabs saw them not only as a raven but also as the Throne of Spica, the Camel, and the Southern Tent (Auriga was their Northern Tent).

Most interesting of all perhaps, Corvus was part of three different cultures' very large constellations. Corvus was the rump of Asad, the Gemini-to-Libra Lion of ancient Arabia, whom I mentioned here in March. Corvus was also part of the large Chinese figure of the Red (or Vermillion) Bird. And finally, our Corvus was the hand of the Hindu's Praja-pati (whom they also represented in Orion). This spring version of Praja-pati, writes R.H. Allen, stood on the rampart of our Scorpion's head, had his thighs marked by Alpha and Beta Librae, his own head represented by Spica (which the Hindus called Citra), and his heart — quite obviously out of place — by Arcturus.

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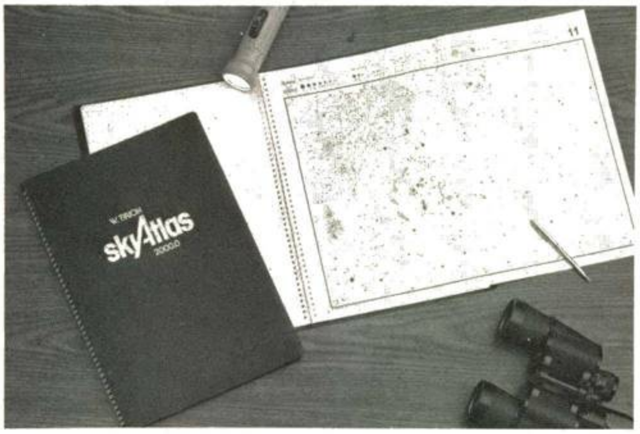

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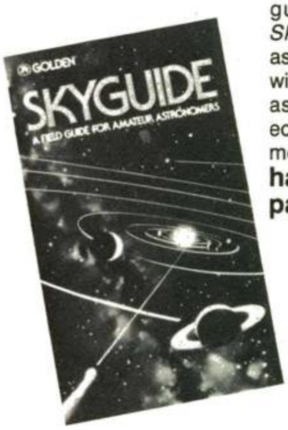

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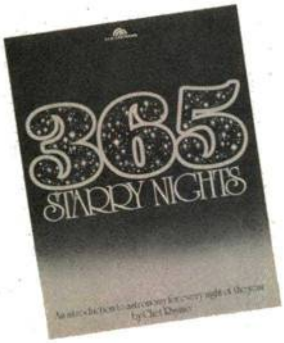

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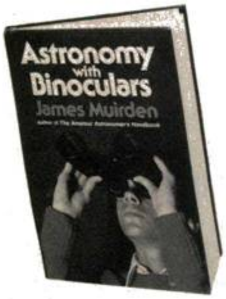

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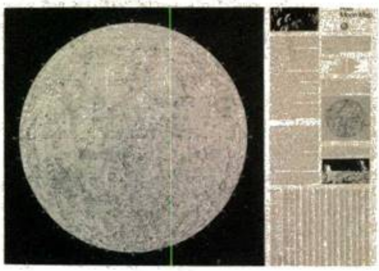

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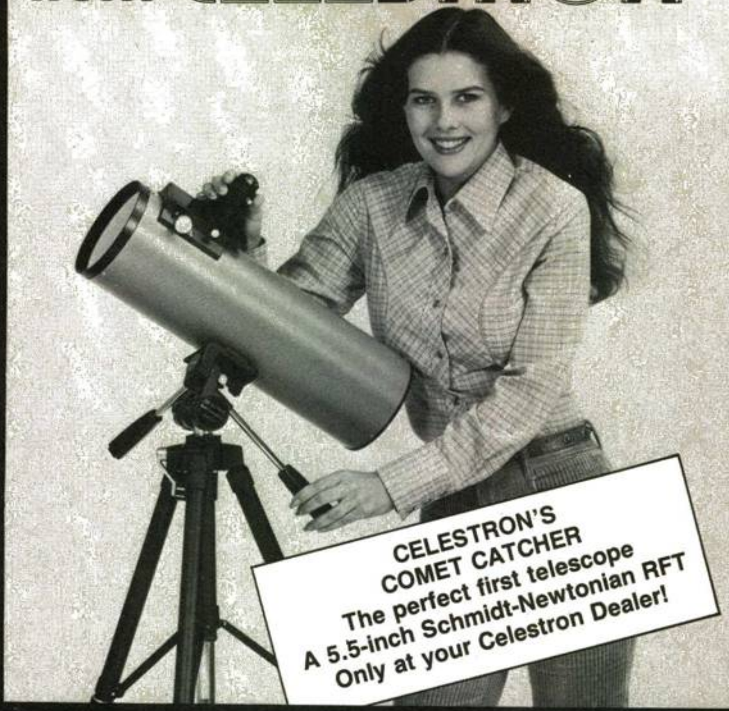

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observing jupiter and saturn

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Likewise, Jupiter's Red Spot and swirling festoons and belts — not to mention the flurry of satellite activity — combine to make it an immensely popular telescopic sight, too.

Okay, so Jupiter and Saturn are guaranteed heart-stoppers at observatory public viewing nights and fine sights in even the smallest of telescopes. But how many of you observers have *seriously* patrolled these two gas giants? If you haven't, this month is an excellent time to start acquainting yourself with the ins and outs of planetary observing. Certainly the two largest planets are a convenient place to start, particularly since Saturn reached opposition late last month, and Jupiter will be at opposition on May 27.

Observing Equipment

You can go out and detect the rings of Saturn or the four bright Galilean satellites of Jupiter with no more than a good strong pair of binoculars, but to study the gas giants you'll need a telescope. The scope need not be elaborate: if you have a small refractor or a Dobsonian-style reflector that doesn't have an equatorial clock drive, you can still make enjoyable observations by letting the planets drift through the telescope's field. But it will be more convenient if you can drive the telescope to track these worlds, and thereby concentrate on looking at the detail they offer — rather than on keeping the planets centered.

In general, the larger the telescope you use, the more you'll see. But it is not simply a matter of aperture. A relatively long focal length is equally as important. The "image scale" of planetary observing is high: you're looking at an object that is at best around one-half minute of arc across — the size of a small lunar crater. So focal ratios of f/8 or greater — and preferably f/10 to f/15 — yield the most convenient focal lengths to observe with.

Observing Technique

Magnification is a critical factor in observing planets, and this is largely dependent on seeing conditions. If the seeing is good, you can use 25x or 30x per inch of telescope aperture before atmospheric turbulence becomes too great. Gauge the useful magnification by experimenting: Saturn will look fine when you find it at 50x in your scope, but when you go to 250x or even 300x, you'll be testing the seeing conditions as well as your telescope's ability. If the seeing is very good, the image will look pretty crisp and steady. If it isn't, you'll know it. It will be like looking at an image at the bottom of a swimming pool. If this happens, back off on the power until the turbulence ceases to distract you.

Since a high-magnification image is so

Jupiter and Saturn Data

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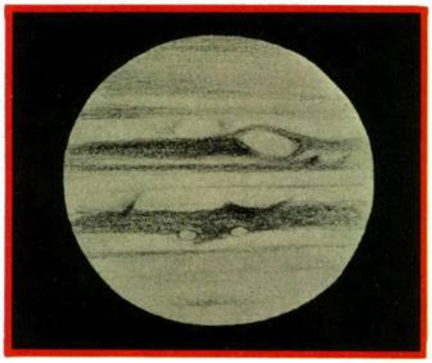
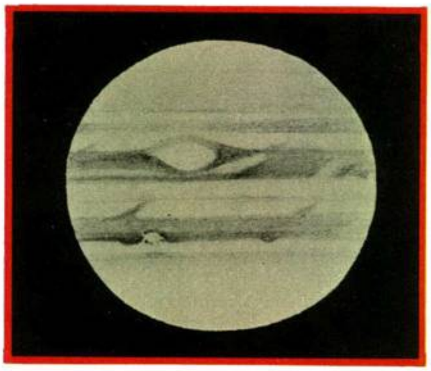
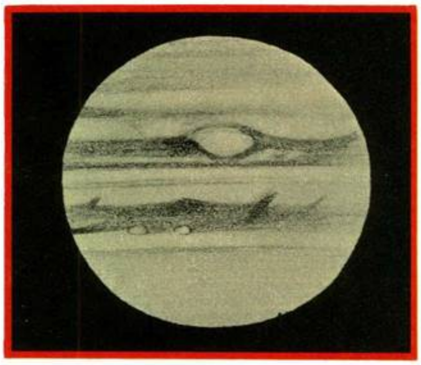
Jupiter		Saturn
	Apparent Diameter (equatorial)	
47″	maximum	19.5″
28″	minimum	14″
	Apparent Magnitude	
−0.5	maximum	−0.2
−1.2	minimum	+1.5
4	Observable Satellites	7
11.86y	Sidereal Period	29.46y
399d	Synodic Period	378d
5.2	Distance from Sun (A.U.)	9.5
11.2	Equatorial Diameter (Earth=1)	9.5
318	Mass (Earth=1)	95.2
3°	Inclination of Axis	27°







Jupiter sketches showing rotational movement by Mark Daniels

touchy, be careful *where* you observe from as well. Make sure that the line of sight to the planet is free from possible interference: don't observe over rooftops, parking lots, or other heat-traps. Expanses of grass or water are both conducive to good seeing.

As far as accessories go, filters are an important consideration for planetary viewing. If you're interested in doing planetary observing, you should buy a set of six glass filters (sold by several companies) that screw in for 1¼-inch or 2-inch eyepieces. A cheaper alternative is a set of gelatine photofilters which you will have to hold up to the eyepiece. Different filters will help to reveal certain surface features on Jupiter and Saturn — so experiment to see what works best for particular features. (As a general rule, red filters will tend to darken surface markings.)

Jupiter's Little Solar System

Jupiter is a fascinating object through the eyepiece. The first thing that most observers notice is the lineup of four bright Galilean satellites: Io, Europa, Ganymede, and Callisto. These moons shine at magnitudes 5.5, 6.1, 5.1, and 6.2 respectively, so they are all easy to see. Go out to the scope some night with a sketchpad full of blank little disks, and sketch the positions of the various satellites. And then go out a few nights later and do it again. Pretty soon you'll have an interesting record of their motion. Even more interesting is monitoring the events that these four chunks of rock undergo: since they are so close to the planet itself, we can observe a seemingly endless array of occultations, eclipses, and transits of the moons and their shadows. *Eclipses* occur when a moon passes through the enormous — several hundred million kilometer — cone of shadow behind the planet. The best time to look for them is about two weeks before and two weeks after opposition, but they can be glimpsed fairly routinely. An *occultation* happens when one of the moons passes behind the disk of Jupiter, and a *transit* occurs when a moon passes across the face — in front — of the planet's disk. A *shadow transit* is when one of the moon's shadow cuts across Jupiter's face. See the box opposite for some events and their dates and times.

Equally as exciting as following the motions of the jovian moons is observing surface detail on Jupiter itself. Famed for its enormous Red Spot, this "failed star" is largely a mass of hydrogen gas — hence the term gas giant. Through a very small telescope, all you may see on the disk is a pair of dark bands that cut across the equatorial region. But on nights of good seeing with slightly larger telescopes, you can see an amazing amount of detail — belts and zones that separate the planet's equatorial, temperate, and polar regions, the great Red Spot, swirls and festoons intertwined with the belts, and subtle colors across the surface.

Jupiter's color is a silvery-cream, and its belts appear deep orange or reddish-brown in medium-aperture scopes. There is a great complexity of action going on here: although a glance may suggest that the planet is relatively serene, its fast-changing detail and rapid rotational motion indicate great violence. If you have a large telescope — say a 12-inch or over — you can closely monitor some of these subtle changes in the belts and in the Red Spot.

The Red Spot is thought to be a tremendous swirling storm whose color and intensity change dramatically. It can appear very different from year to year and even completely disappear in small scopes. In telescopes of 10-inch aperture or above, you can observe internal detail in the Red Spot — dark reddish brown features with a contrasting border. In the past few years it has been rather pale, but see what color you think the spot is during this opposition.

The Great Ringed World

Saturn is also a fascinating target. The rings are visible in any telescope, and its creamy-white to khaki color becomes apparent even in binoculars. Saturn has a system of rings, termed the A ring, B ring, and C ring as you move in toward the planet. The innermost C (crepe) ring

Astronomical "Seeing"

Beginning observers are often tempted to crank up the magnification on their scopes as much as possible to see as much as they can. This is simply asking for trouble, however, because too much power magnifies atmospheric disturbances and produces lousy images. Planetary observing means high resolution. You're working on a large image scale, looking at small objects at high magnification. Because of this, seeing conditions — the quality of the atmosphere you look through — play an important role in determining how good the planets will look in your eyepiece.

To help in finding out if a night is a good one for observing planets, astronomers have devised a five-point scale that ranges from terrible to perfect seeing.

Level 1: *Severely disturbed skies.* Objects in the sky appear to be jumping around and twinkling even to the naked eye. Even low-power views through the scope are uselessly shaky.

Level 2: *Poor seeing.* Low-power images in the telescope are pretty steady, but medium magnifications result in unsteady views. The sky is still disturbed.

Level 3: *Good seeing.* Conditions are fairly good; you can get away with using about half of the useful magnification for your telescope. But high powers only produce unfocused, fidgety planets.

Level 4: *Excellent seeing.* You can use medium powers and get a crisp, stable image. High powers present a good view, but are a little soft.

Level 5: *Superb seeing.* Practically any power eyepiece that you have for your telescope seems to produce a good crisp image that stays put in the field. These nights are very rare!

There is an unusual relationship between seeing and *transparency*. There are nights when the sky appears to be very transparent (dark) and yet even in your finderscope objects are twinkling and jumping around. In this case, all you can observe are extended deep-sky objects at low resolution. And there are nights when the seeing is very steady, but there is a thin layer of haze or sky brightness. When this happens, dim objects are wiped out, but planetary detail may be extraordinarily crisp.

If the sky is at level 1 or level 2, you probably shouldn't consider doing any serious planetary observing. The high magnifications involved will just aggravate the problem; you'll see fuzzy images dancing all around the field. If the sky is at levels 3 through 5, however, take your telescope and eyepieces out and enjoy!

Jovian Satellite Events

The following is a compilation of jovian satellite shadows, transits, and eclipses visible from the continental U.S. during the month of May 1983. The first two columns provide the day and time in Universal Time, the third column the moon involved, and the fourth column lists the event.

Date	Time (U.T.)	Moon	Event
May 1	8:03h	Io	shadow begin
	8:41	Io	transit begin
	10:14	Io	eclipse disappearance
	10:50	Io	transit end
2	5:16	Io	eclipse disappearance
	6:52	Europa	shadow begin
	8:01	Io	occultation reappearance
	8:04	Europa	transit begin
3	4:42	Io	shadow end
	5:16	Io	transit end
4	5:05	Europa	occultation reappearance
6	4:42	Ganymede	transit end
9	7:09	Io	eclipse disappearance
10	4:26	Io	shadow begin
	4:52	Io	transit begin
	6:37	Io	shadow end
	7:01	Io	transit end
11	4:11	Io	occultation reappearance
	4:13	Europa	eclipse disappearance
	7:22	Europa	occultation reappearance
13	4:26	Ganymede	shadow begin
	5:59	Ganymede	transit begin
	6:44	Ganymede	shadow end
	8:01	Ganymede	transit end
16	9:03	Io	eclipse disappearance
	6:20	Io	shadow begin
	6:36	Io	transit begin
	8:31	Io	shadow end
	8:46	Io	transit end
18	5:55	Io	occultation reappearance
	6:49	Europa	eclipse disappearance
	9:38	Europa	occultation reappearance
20	8:24	Ganymede	shadow begin
23	10:57	Io	eclipse disappearance
24	8:14	Io	shadow begin
	8:20	Io	transit begin

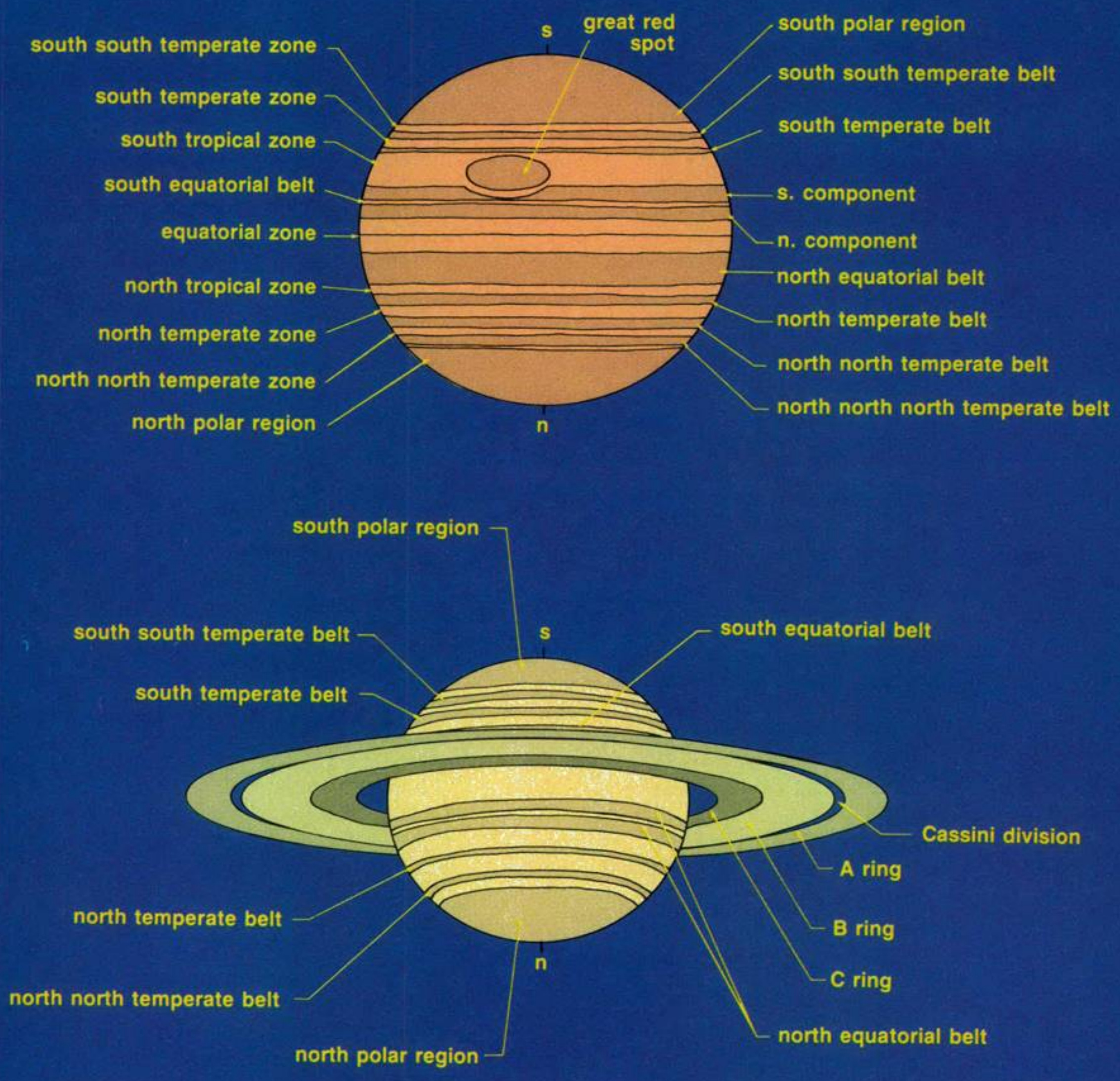
For a complete tabulation of jovian and saturnian moon events, see the *Astronomical Almanac*, published by the U.S. Naval Observatory in Washington. It is an indispensable reference work for planet watchers. You can look for it at a library or send $16 (hardcover) to the U.S. Government Printing Office, Washington, DC 20402.

Eastern Elongations of Saturnian Moons

This table lists what you'll need to identify seven of Saturn's brightest satellites: Titan, Rhea, Dione, Tethys, Iapetus, Enceladus, and Mimas. The first two columns give the date and time of eastern elongation for the satellite listed in the third column. Note that Iapetus does not undergo an eastern elongation during May (it has an orbital period of some 79 days).

Date	Time (U.T.)	Satellite
May 1	6.0h	Enceladus
2	7.0	Tethys
	10.0	Rhea
	10.5	Mimas
6	7.7	Dione
	13.8	Titan
9	11.3	Enceladus
11	10.6	Rhea
16	9.3	Tethys
17	6.3h	Dione
	10.9	Mimas
19	6.6	Tethys
20	10.3	Enceladus
22	11.4	Titan
28	4.9	Dione
30	9.3	Enceladus
31	15.5	Mimas
July 18	16.8	Iapetus

Belt and Zone Nomenclature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great red spot
south south temperate zone
south temperate zone
south tropical zone
south equatorial belt
equatorial zone
north tropical zone
north temperate zone
north north temperate zone
north polar region
n
south polar region
south south temperate belt
south temperate belt
s. component
n. component
north equatorial belt
north temperate belt
north north temperate belt
north north north temperate belt
south polar region
south south temperate belt
south temperate belt
s
south equatorial belt
Cassini division
A ring
B ring
C ring
north equatorial belt
north temperate belt
north north temperate belt
n
north polar region

The Association of Lunar and Planetary Observers

Do you want to know more about observing Jupiter and Saturn? The *Association of Lunar and Planetary Observers* (ALPO) started in 1947 as a clearinghouse for observations of solar system objects, and has kept interested backyard astronomers in contact with each other and informed of recent events in planetary astronomy. The ALPO publishes a quarterly journal filled with articles, book reviews, and planetary photos and sketches called *The Strolling Astronomer*, which costs $12 for six issues — $14 outside the U.S. For more information, write Dr. Walter H. Haas, Director, Box 3AZ, University Park, NM 88003.

is pretty difficult to observe in small backyard scopes, because it is so diffuse. However the thicker planes of ice and rock — the A and B rings — are easily seen, as is the dark band between them called Cassini's Division. We are currently viewing the north side of the rings.

The ringed planet doesn't offer as much surface detail as does Jupiter, but still it reveals dusky clouds and bands. Again, experiment with different filters — red, orange, blue, etc. — and see what works best. It may well turn out that a filterless view is the most pleasing.

Saturn has 15 moons, only seven of which are bright enough to be observed even with large backyard instruments. The satellites and their magnitudes at opposition are: Titan (8.4), Rhea (9.7), Tethys (10.3), Dione (10.4), Iapetus (11.0), Enceladus (11.8), and Mimas (12.1). It can be very confusing trying to identify a bunch of 10th to 12th magnitude dots floating around in your eyepiece along with field stars. By using the table on page 54, you can catch a certain saturnian moon at its greatest eastern elongation in its plane of orbit and thereby identify it as it moves against the background stars.

If you haven't been actively gazing at the planets with your telescope, take advantage of the return of the warm months and experiment with magnification, filters, and observing technique. You will surely be delighted at the features, bands, belts, rings, and numerous satellite interactions of the two grandest planetary bodies in our solar system.

— *David J. Eicher*

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16″ Equatorial Reflector: **$1185.00**, complete! The Giant-Aperture, Deep-Space Telescope You Never Thought You Could Afford... Until Now

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Manufactured exclusively for Crown Optics by Meade Instruments Corp., the World's largest manufacturer of reflecting telescopes for the serious amateur, the DS-10 and DS-16 make available to the average amateur visual and photographic capabilities only dreamed of until now. Unlike competing large-aperture telescopes, the Meade DS-Series Telescopes include **Equatorial Mounts** as standard equipment: you track effortlessly along **one** axis, not along 2 simultaneous axes as with an alt-azimuth mounting. Add the optional Electric Motor Drive System and you're ready for fully automatic tracking and the deep-space photography you never thought possible.

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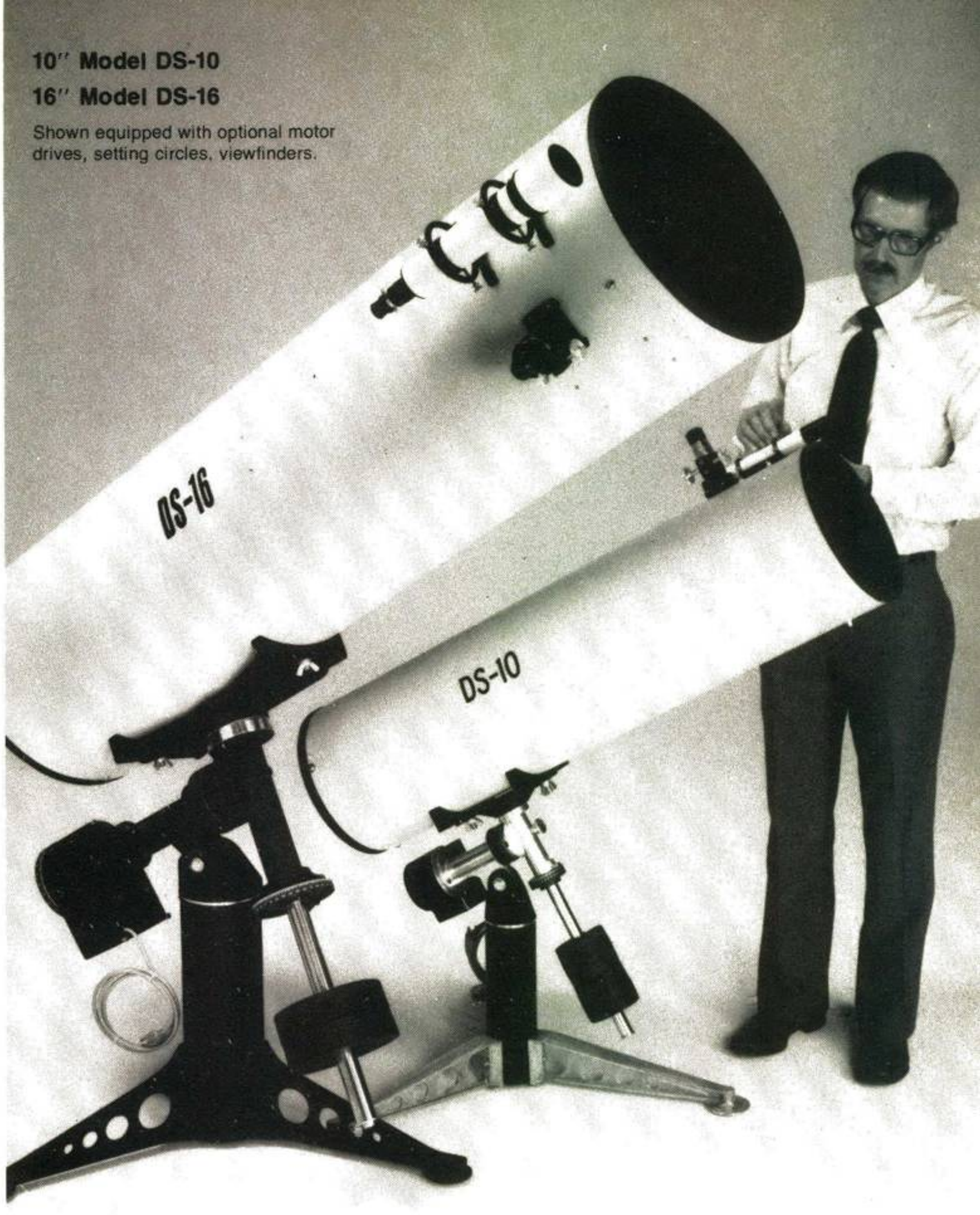
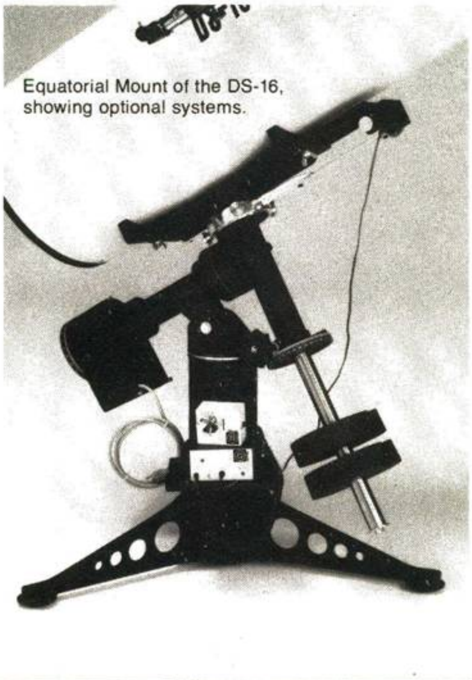


10″ Model DS-10
16″ Model DS-16
Shown equipped with optional motor drives, setting circles, viewfinders.


Equatorial Mount of the DS-16, showing optional systems.

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#897	**Electric Motor Worm-Gear Drive System (115v./60Hz) for DS-16**	**155.00 ppd.**

See our ad on the next page for the wide array of other optional accessories for the DS-10 and DS-16. These include: higher- and lower-power eyepieces; viewfinders; telenegative amplifiers; nebular filters; drive correctors and photoguide telescopes for long-exposure photography; camera adapters. The giant Meade #680 Focuser may also be ordered in place of the standard focuser on the DS-10 and DS-16. See Bulletin DS for details.

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6— **Model 680** — Accepts both 1¼″ and 2″ eyepieces. Full 3″ travel for photo or visual observing with 6″ to 16″ telescopes. **$44.95 ppd.**

ACCESSORY CASES— For secure storage of eyepieces, Barlows, filters.
7— **Model 54:** Thick-wall polyethylene with latch and handle. Holds 7 eyepieces & Barlow, filters. Dims. 12″ × 8″ × 3¾″ **$12.50 ppd.**
8— **Model 50:** Luggage-quality metal case with 2 latches, handle; foam custom fits to your accessories.
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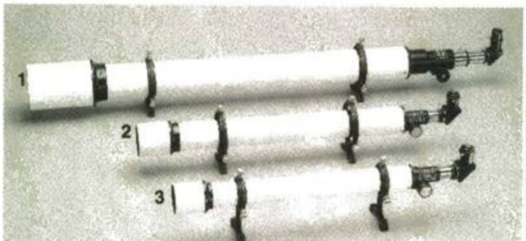
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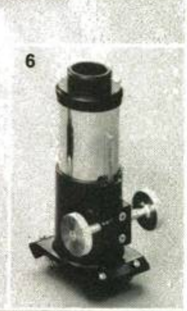
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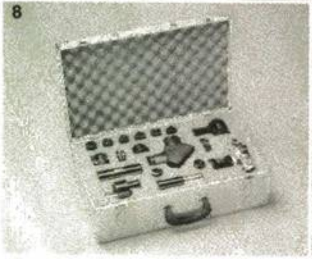
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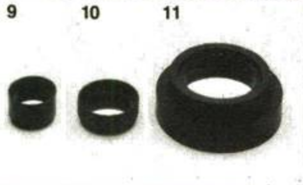
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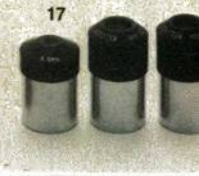
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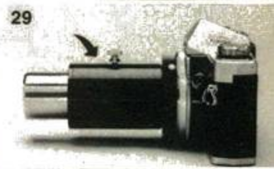
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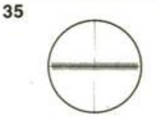
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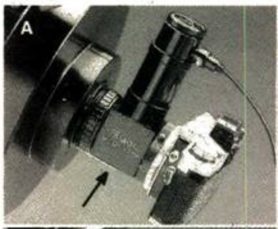

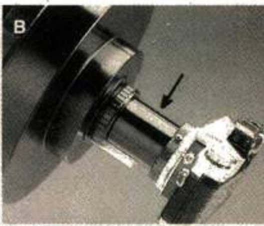

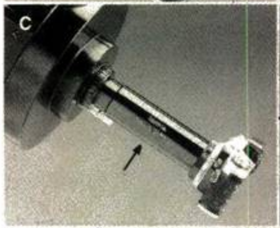

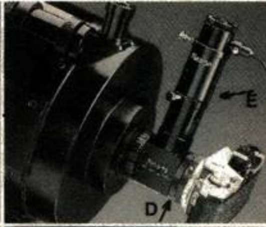

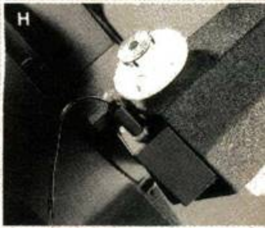

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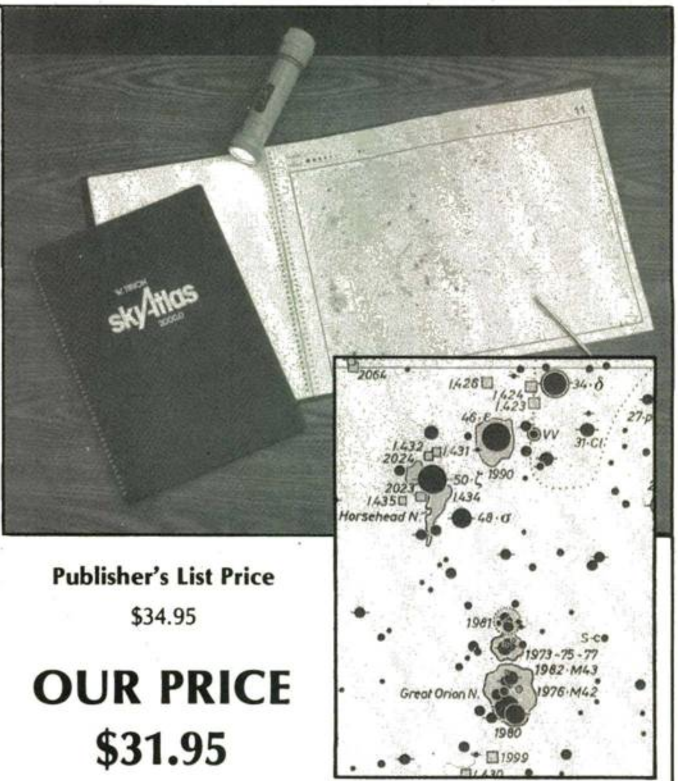

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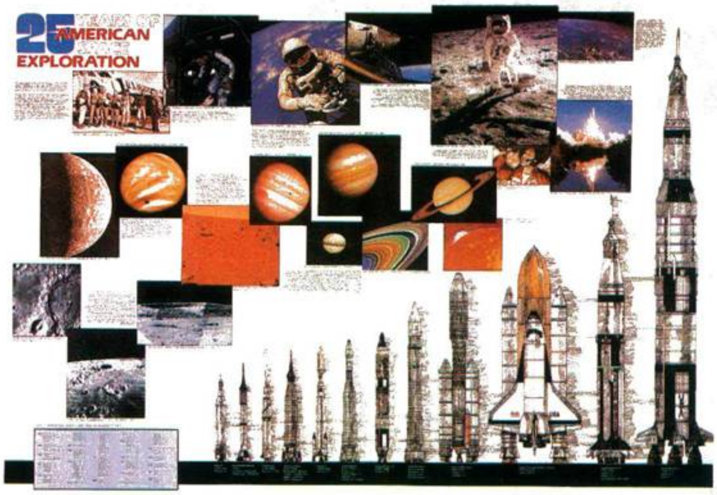
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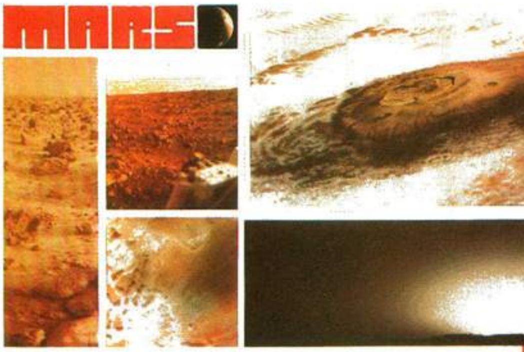

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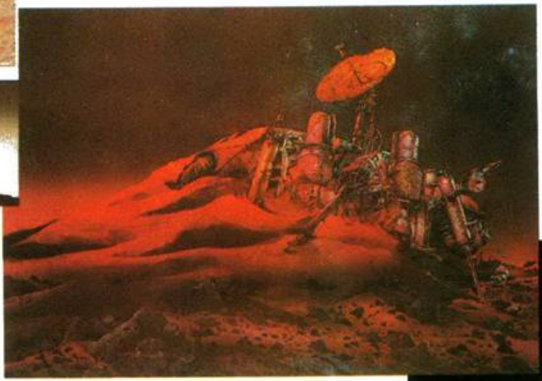

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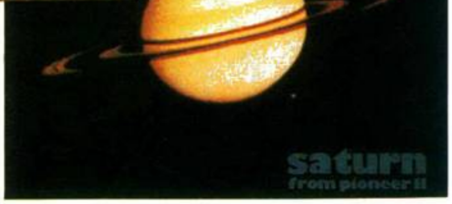

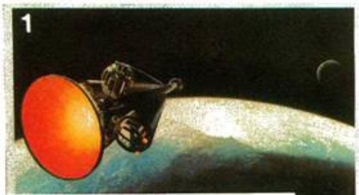

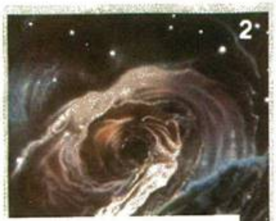

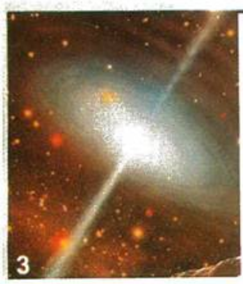

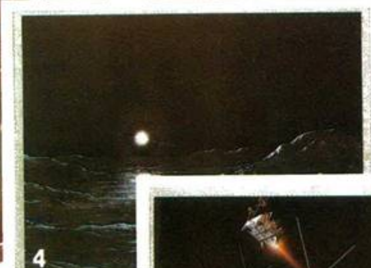

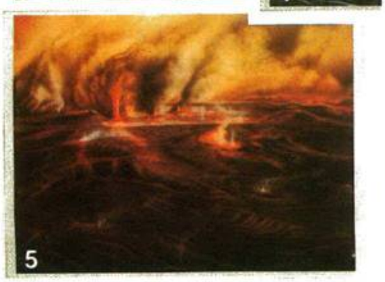

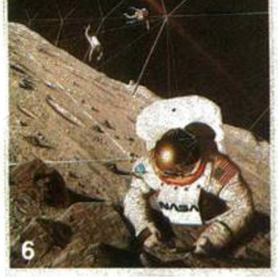

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ASTRO NEWS

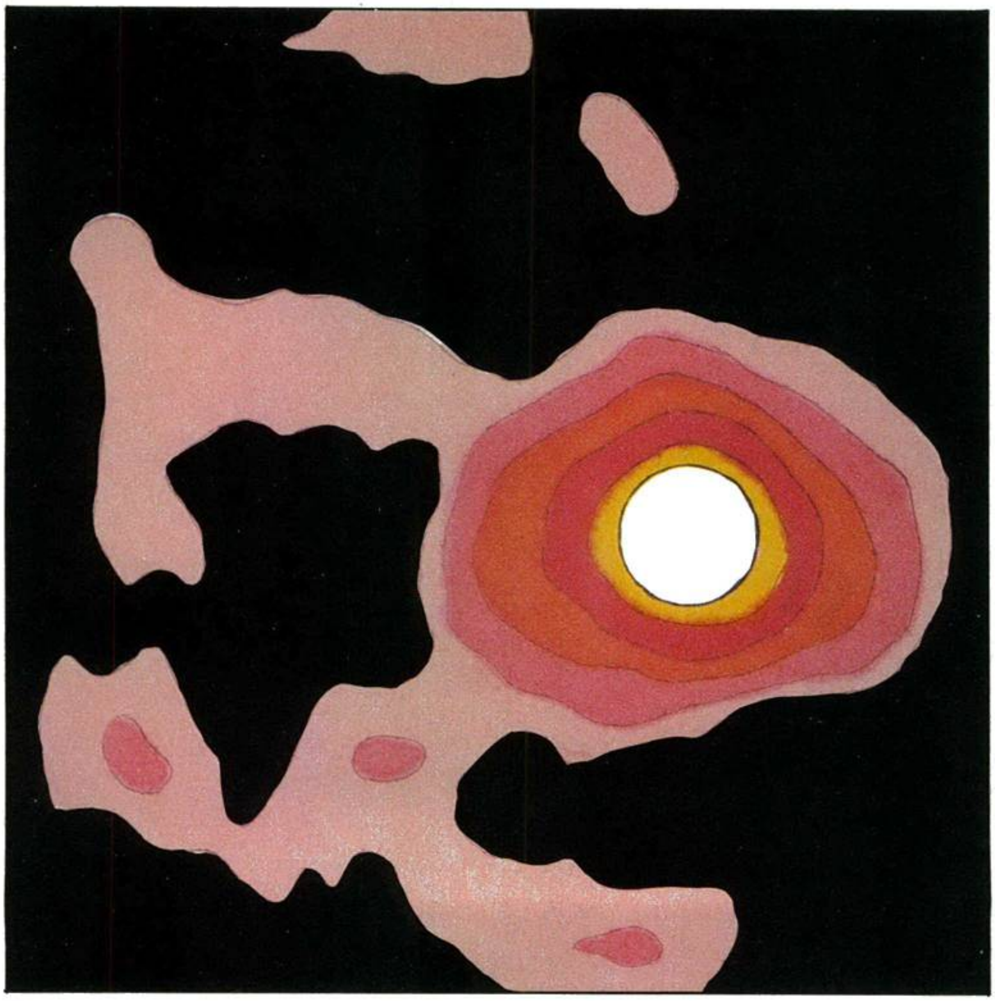
Stellar Chromospheres Up Close

A new imaging technique may revolutionize our understanding of stars. According to Jacques Beckers, director of the Multiple Mirror Telescope Observatory in Arizona, a technique known as differential speckle interferometry may yield a resolution of $\frac{1}{80}$ second of arc — small enough to probe the tenuous outer atmospheres of stellar giants.

Developed in the early 1970s, speckle interferometry is a technique that allows astronomers to eliminate the effects of atmospheric turbulence. Starlight is disrupted in its passage through Earth's turbulent, dusty atmosphere. In speckle interferometry, astronomers take a large number of very brief exposures of stars — on the order of $\frac{1}{100}$ second. Each of these exposures contains an image of the star that is distorted. By computer-processing a lot of photos, the undistorted stellar image can be reconstructed.

Beckers' technique is a variation on this theme. He obtains two speckle images simultaneously — one in the emission line of hydrogen alpha (6563 A), and another in a segment of the continuous spectrum at about 6568 A. Red supergiants are thought to have very cool, very distended outer atmospheres. The Hα image shows these extended layers, while the continuum image provides a point source for reference. Beckers uses the continuum to determine the effects of Earth's atmosphere on the incoming light, then applies the result to the Hα image. The remaining information is a map of the star's outer layer, or chromosphere.

The original work was done on the 3.8-meter telescope at Kitt Peak National Observatory, producing a resolution of about $\frac{1}{40}$ arc-second. But Beckers hopes to improve resolution to $\frac{1}{80}$ arc-second later this year by applying the same techniques to the MMT, which has an effective diameter of 6.9 meters. This work has already produced some surprises. For example, features that appear to be titanic prominences extend for several stellar diameters in an image of Alpha Herculis. "But it is too early to say for certain," adds Beckers. "The technique is still under development."



The disk of the red supergiant Alpha Herculis is white in this map of the star's tenuous chromosphere, obtained by differential speckle interferometry. The elongated portion appears to be an enormous prominence. Image courtesy of Jacques Beckers, Multiple Mirror Telescope Observatory.

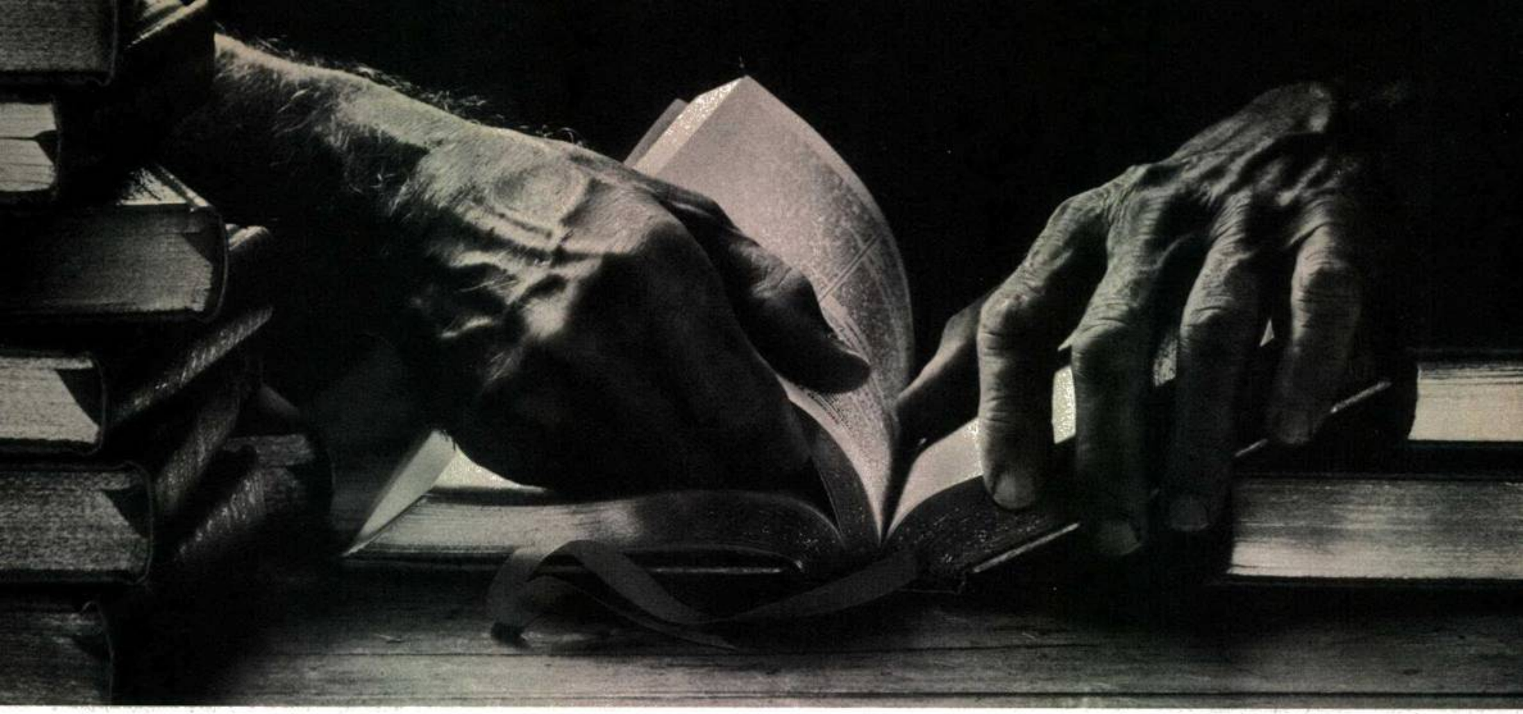
Epsilon Aurigae's Latest Antics

Epsilon Aurigae is an eclipsing binary with one of the longest known periods — 27.1 years. The star lies about 3° southwest of the constellation's brightest star, Capella, and marks the apex of "The Kids," an asterism formed by Epsilon, Zeta, and Eta Aurigae. The system's visible component is an F-type supergiant about 15 times the mass of the Sun and about 2,000 light-years distant.

While the star's 0.8 magnitude drop in brightness is clearly caused by an orbiting companion passing between it and Earth, astronomers have spent the last 80 years trying to discover just what that object is. Another of the star's rare eclipses began in July 1982, and its year-long minimum began in December. According to Robert Stencel of NASA's Astrophysics Division in Washington, "The new data received may provide the breakthrough to understanding the invisible component of the Epsilon Aurigae system."

Observing programs range from photometric measurements by both amateur and professional astronomers to spectroscopic observations with the International Ultraviolet Explorer satellite. Coverage of this eclipse is important since observations of the last three minima supplied more questions than answers. In 1903, the German astronomer H. Ludendorff proposed that the eclipsing object — which has never been detected — was a giant meteorite swarm. After digesting the puzzling results of the 1929 minimum, Yerkes Observatory astronomers Gerard Kuiper, Bengt Stromgren, and Otto Struve suggested that Epsilon Aurigae's companion was a cool, very rarified star. They argued that the object could not be detected because it emitted only low-energy infrared radiation. After the 1955 minimum, both a disk-shaped proto-planetary nebula and weird interacting gas streams were considered as possible models for the secondary. And when black holes hit the press in 1971, the companion of Epsilon Aurigae was suspected almost immediately.

Intrinsic variations in the visible star of the system don't make things any easier. The supergiant undergoes Cepheid-like pulsations that change its brightness in a 100 to 120 day cycle. Yet although the present eclipse doesn't end until 1984, astronomers are already analyzing the new data in the hope of finding a model that works. "The data, particularly from the infrared," Stencel said, "hint at characteristics that were never before observed." For example, James Kemp at the University of Oregon observed a sudden change in the polarization of visible light at second contact last December. This *could* occur when light from the primary shines through dust grains with similar orientations — such alignment may be caused by



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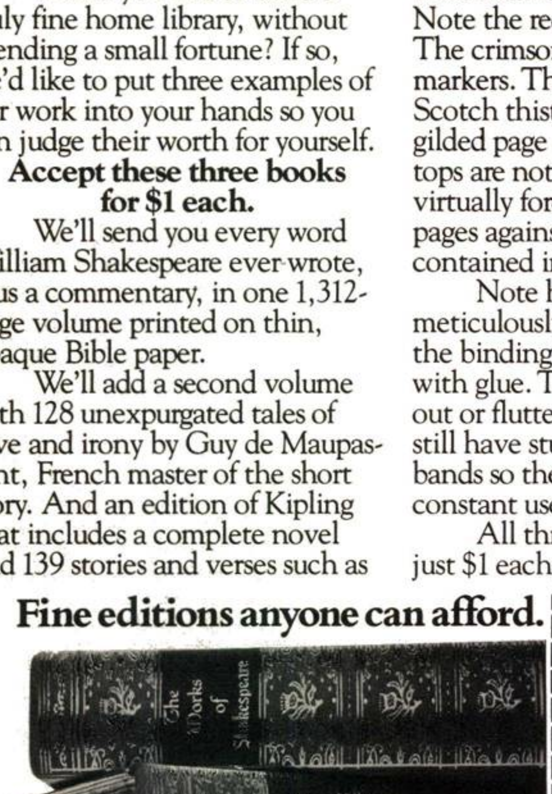

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Ultraviolet spectroscopy with the IUE shows steady emission from singly ionized magnesium. According to Stencel and co-workers Robert Chapman and Yoji Kondo of NASA's Goddard Space Flight Center, the emission's constancy suggests that it arises in an extended region around the eclipsing object. In addition, both ultraviolet spectroscopy and infrared photometry indicate that the secondary has an equilibrium temperature below 1,500° Kelvin.

Early results from the mysterious eclipse suggest that the companion is a cool object (about 1,000° K), possibly with a well organized central core — which would account for the polarization jump near second contact. The magnesium emission may originate in an extended region of hot gas surrounding the strange secondary. Interactions with the F star's stellar wind may be responsible for heating the envelope of ionized gas.

"This hypothetical design," remarks Stencel, "implies various continuing changes that should be observable." For example, if the polarization changes near second contact were indeed caused by aligned dust grains, then further abrupt changes should occur at third contact late this year. So far, no one can determine the nature of the eclipsing body until all the data are analyzed. After all, the eclipse has more than a year to go — Epsilon Aurigae may still have some surprises in store.

How Will the Next Supernova Be Found?

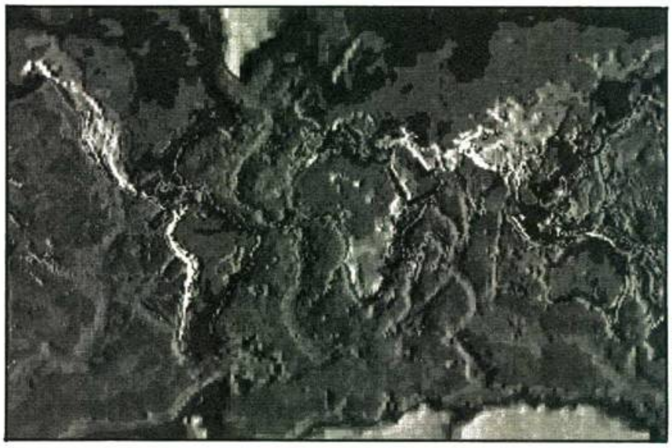
The last supernova visible from Earth blazed forth in 1604, a few years before the invention of the telescope. Ever since, astronomers have been awaiting the next — which is long overdue if we can judge by what happens in other galaxies. Unfortunately, to be visible, a supernova occurring in our own Galaxy would have to lie within about 5 kiloparsecs (16,000 light-years) of us or it would be too obscured to be seen at optical wavelengths. As a result, over the past 400-odd years we have probably missed observing several Milky Way supernovae that weren't close enough to be spotted through light-years of dust.

This line of reasoning has led Woodruff T. Sullivan, III, an astronomer at the University of Washington, to propose (in the *Publications* of the Astronomical Society of the Pacific) that radio observations in the microwave region of the spectrum — where the Galaxy is relatively transparent — may offer a better chance of finding a "local" supernova. The few extragalactic supernovae that have been observed have signal strengths that indicate that had they occurred anywhere in our own Galaxy, they would have been among the strongest microwave sources in the sky. If these are typical for most supernovae, then any antenna working in the 2-cm to 20-cm wavelength region is probably able to pick up the next Galactic supernova.

Such a discovery could be made accidentally, since the supernova's signal would flood a receiver system with a loud burst of noise. All that would be necessary, Sullivan notes, is that the supernova be in the "angle of response" for the antenna — *and that the observer investigate the anomaly*.

According to Sullivan, this last proviso is the crux of the matter, because radio surveys tend to accumulate observations for some time before they are examined in detail. It is all too easy for an observer, examining his output days or weeks later, to assume that any given strong signal is due to a "system glitch" or interference. And unless careful follow-up checks are made, the supernova's signal will be ignored.

Sullivan emphasizes that the ideal program to find supernovae would use a medium-size antenna that scans the whole sky rapidly at microwave wavelengths — a search that is already being done for other purposes by military, civilian, and space-reseach radar antennas. In these cases, the discovery would be made only if the operator were alert and had the initiative to establish that the suspect source was fixed in sidereal coordinates. And since there is some doubt that even a radio astronomer would follow up on such a signal, Sullivan asks how many Milky Way supernovae have already been discovered — and dismissed?


JPL/NASA photo.

Are Earth's oceans primordial?

Are the Oceans as Old as the Earth?

Look at a photograph of Earth seen from space, and what do you see? Water, in all its myriad forms — collectively called the hydrosphere. But when did our planet acquire its most characteristic feature, and how?

Scientists have long believed that Earth's oceans appeared relatively late in its history — long after the asteroid bombardment that marked the end of its formation, and after a further period marked by a thick, hot, reducing atmosphere, which eventually escaped into space. Later still, radioactive heating in the Earth produced convection and volcanic activity, which in turn released the volatiles we see in today's relatively thin and cool atmosphere. Only then, according to theory, did Earth's surface environment allow oceans.

According to A. Henderson-Sellers of the University of Liverpool, England, and J. Graham Cogley of Trent University, Canada, our planet may have developed very differently. Writing in a recent issue of *Nature*, Henderson-Sellers and Cogley use a number of new interdisciplinary models of Earth's formation and early evolution to argue that the hydrosphere may predate even the end of the planet's accretion from the proto-solar nebula.

These new models suggest that heat generated by continuing impacts kept enough of the Earth melted to start convection and the formation of a heavy core when Earth was as little as one-tenth its present size. Further, much of the ejecta from impacts of low-density icy bodies such as comets must have escaped the weak gravity of the early Earth, only to be swept up later. This would produce an early crust rich in volatile elements. They could result in the formation of oceans long before radioactive heating and its subsequent outgassing could have an appreciable effect.

The scientists also believe that any primordial reducing atmosphere would have been so unstable under these conditions as to have decayed and escaped faster than Earth could form. Hydrogen would have escaped from the upper atmosphere, since the temperature inversion at the tropopause, which restricts such evaporation today, did not yet exist. The other chief components, ammonia and methane, are destroyed by sunlight. Thus gases able to produce a strong greenhouse effect will not exist long enough to trap heat in the atmosphere and will soon let it cool below the boiling point of water.

Early oceans could help to account for the apparent contradiction between a Sun believed to have been cooler than today and an Earth known to have been at least as warm as it now is. The early crust would have been too weak to support continents, and the only structures which might have stood above water were the low rims of impact craters. So there would have been little land upon which glaciers could form, and a consequent shallow planetary ocean would have been extremely resistant to freezing. This could have had a strong stabilizing influence on the climate: a buffer balancing a warming Sun against a cooling Earth.

Yet another problem which could be solved by the early appearance of oceans is the early appearance of life. If Henderson-Sellers and Cogley are right, then far more time than previously assumed would be available for the aqueous development of organic molecules. *Donald F. Robertson.*

NASA Weightlessness Study Needs Volunteers

Are you a healthy male, aged 35 to 50, and either sedentary or active? If so, NASA may have a job for you this summer. Because of the problems that have cropped up with

Practical Astronomy With Your Calculator, 2nd edition, by Peter Duffett-Smith. This handy book tells you how to use a scientific calculator to convert local standard time to sidereal time, find the time of moonrise and set — and more. Assumes no specialized knowledge, provides complete examples. 188 pages, paperback, **$10.50.**

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The Beginner's Guide to Computers, by Robin Bradbeer, Peter De Bono, and Peter Laurie. If you're looking for a first book on home computers, this is it. Written with the complete novice in mind. Fully indexed with glossary. 208 pages, paperback, **$10.50.**

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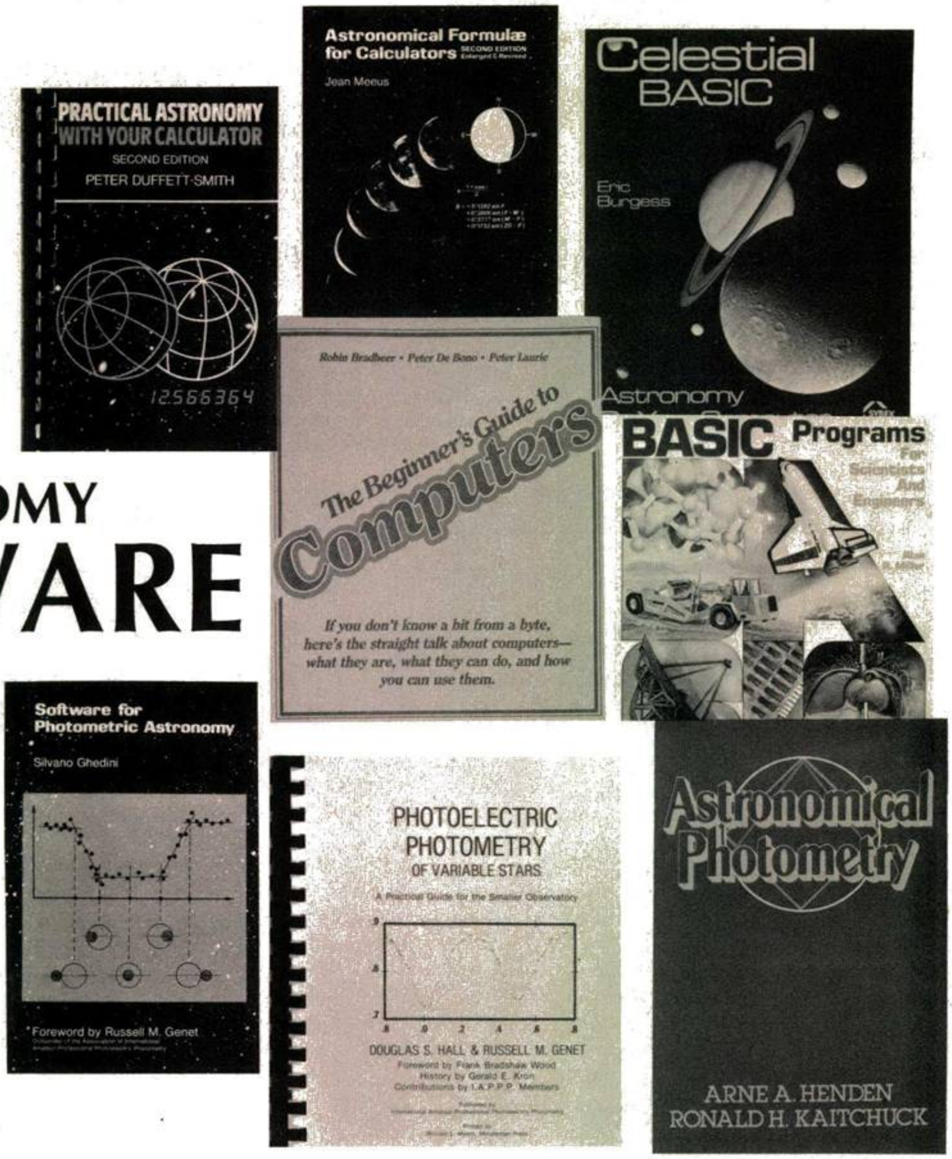
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ASTRO NEWS

motion sickness among the Shuttle astronauts — problems that may seriously affect their ability to carry out routine tasks in space — NASA has embarked on a study that will test the effects of weightlessness on the heart and blood pressure regulation. It will be conducted at Ames Research Center in Mountain View, California.

The study, which will last 54 days, will simulate weightlessness by two 10-day periods of bed rest, which are to mimic two Shuttle flights. Each "flight" will be followed by a two-week recovery period.

One of the purposes of the study is to examine the role that aerobic exercise training (such as running or bicycling) has on Shuttle crew members. Comparisons will be made between the performance of sedentary people and those who undertake vigorous exercise at least five times a week. Another aspect of the study will focus on the amount of time needed for full recovery between "flights."

Still interested? After some preliminary screening tests, the 10 volunteers chosen (5 sedentary and 5 athletic) will be admitted to the Ames Human Research Facility. The test is scheduled to begin on July 5th. All subjects chosen will be paid for their time during the study and will be allowed to return home for a few days during each recovery period. Anyone interested should phone (415) 965-5118.

ASTRO CALENDAR

April 23	**Astronomy Day.** Astronomers everywhere are urged to set up telescopes and show friends, neighbors, and the general public a view of the heavens. Members of the Astronomical League will celebrate Astronomy Day on May 14.
May 20-23	**Joint Meeting of the American Association of Variable Star Observers (AAVSO), Royal Astronomical Society of Canada (RASC), and Association des Groupes d'Astronomes Amateurs (AGAA).** Quebec City, Quebec, Canada. Contact: AAVSO, 187 Concord Ave., Cambridge, MA 02138 or Dr. Rejean Dutil, Dept. de Physique, Pavillon Vachon, Universite Laval, Ste.-Foy, Quebec G1K 7P4, Canada.
May 27-30	**Riverside Telescope Maker's Conference.** Big Bear, California. Contact: Clifford Holmes, 8642 Wells Ave., Riverside, CA 92503.
June 3-6	**Convention of the Mid-States Region of the Astronomical League.** William Jewell College, Liberty (Kansas City), Missouri. Contact: Tom Martinez, Chairman, 1208 Somerset Ct., Blue Springs, MO 64015.
June 8-12	**Texas Star Party,** Fort Davis, Texas. Annual meeting of the National Deep Sky Observers Society will be held in conjunction with the Star Party. Contact: T.S.P. '83, Dept. A, 2709 Colonial Dr., Carrollton, TX 75007. Phone (214) 242-4908.
June 10-11	**13th Annual Apollo Rendezvous and Telescope Fair.** Dayton, Ohio. Sponsored by the Miami Valley Astronomical Society and the Dayton Museum of Natural History. Contact: Coordinator — Apollo Rendezvous, 2629 Ridge Ave., Dayton, OH 45414.
June 13-19	**Joint Meeting of the Astronomical Society of the Pacific and the Western Amateur Astronomers,** on the Kona coast of the Big Island of Hawaii. Contact: Hawaii Meeting, A.S.P., 1209 23th Avenue, San Francisco, CA 94122.
June 19-22	**American Astronomical Society** (professional meeting). Minneapolis, Minnesota. Contact: AAS, 1816 Jefferson Pl., N.W., Washington, DC 20036.
July 14-16	**4th Annual Fairborn Symposium,** "Microcomputers in Astronomy." Fairborn, Ohio. Sponsored by IAPPP and AAS/SIGUMA. Groundbreaking for Fairborn Observatory one-meter telescope, July 15. Contact: Microcomputers in Astronomy, c/o Fairborn Observatory, 1247 Folk Rd., Fairborn, OH 45324.
July 16-24	**Florida Spaceweek '83.** Many cities need people. Contact: Florida Spaceweek Committee, 993 Macco Rd., Cocoa, FL 32922.
July 22-23	**Spaceweek-Upstate,** a weekend for the amateur astronomer. Greenville, South Carolina. Contact: Piedmont Advocacy for Space, Box 197, Fair Play, SC 29643.
July 26-30	**ALCON '83** — national convention of the Astronomical League. Jacksonville, Florida. Contact: Michael Reynolds, P.O. Box 1170, Jacksonville Beach, FL 32250.
August 5-6	**Stellafane.** Springfield, Vermont. Contact: Dennis di Cicco, 60 Victoria Rd., Sudbury, MA 01776.
October 8	**Telescope User's Clinic.** Sponsored by the Western Observatorium. Rio Hondo College, Whittier, California. Contact: Western Observatorium, 13215 E. Penn St. #411, Whittier, CA 90602. Phone Bob Ferguson at (213) 795-4181.
October 27-29	**Great Plains Planetarium Association Conference.** Hastings, Nebraska. Contact: Mitch Luman, J.M. McDonald Planetarium, 1330 N. Burlington, Hastings, NE 68910.

Meeting notices to appear in AstroCalendar must be submitted at least three months in advance of the meeting date. Most organizations appreciate your enclosing a long (business-size) self-addressed, stamped envelope along with your request for information.

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ANNOUNCEMENT — KRAMO III model rocket meet. June 11-12, Wichita, KS. A Streamer Duration, ½A Parachute Duration, A Superroc Duration, A Boost Glide, C Eggloft Altitutde, Predicted Duration, Open Spot Landing, Plastic Model. Contact Mark Johnson, 3532 S. 154 E. St. Wichita, KS 67232. Phone (316) 733-4804.

ANNOUNCEMENT — The Plutonian Society's Mini-Observatory Network is setting up a photographic patrol of Markarian Galaxies for supernovae. If you have at least an 8" scope and can make long (30-minute) exposures, and wish to help out, please let me know. Foreign observers welcome. Contact Gary Anderson, 9030 Buchanan Dr., Brighton, MI 48116.

ANNOUNCEMENT — The American Association of Variable Star Observers (AAVSO) will be holding its spring meeting in Quebec City, Quebec, Canada, May 20-22, in conjunction with the Royal Astronomy Society of Canada (RASC) and l'Association des Groupes d'Astronomes Amateurs (AGAA). The meeting will include scientific paper sessions, a joint banquet, social get-togethers, a tour of Quebec City, and an optional day tour to l'Observatoire du Mont-Megantic on the 23rd. Of special interest will be the exhibit contest in 12 different categories of astronomy ranging from solar, deep space, and variable stars to radio astronomy in subject matter. Entries will be judged and prizes awarded. For further information contact AAVSO, 187 Concord Ave., Cambridge, MA 02138.

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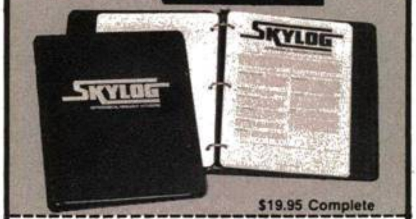

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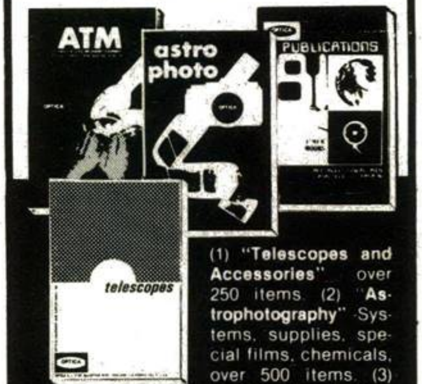

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Astronomers first measured temperatures and luminosities of stars at the turn of the century. They discovered a wide range of types of stars that composed the "main sequence" of stellar evolution. A small number of them had cool, red surfaces many thousands of times brighter than the Sun. These unusual stars perplexed researchers: since cool surfaces emit small amounts of light per unit area, they had to be truly enormous by ordinary standards — hundreds of times the diameter of the Sun — to account for their great luminosities. They were appropriately dubbed *red supergiants*.

The prototype of this class of stars is Alpha Orionis — the brilliant red star in the upper left shoulder of Orion the Hunter. According to Paul Kunitzsch, its common name, Betelgeuse (pronounced BET'L - joos), comes from the Arabic expression "yad al-jawza," meaning "Hand of the Giant One," after the figure of the ancient constellation. In contrast with the many bluish-white stars that compose Orion, Betelgeuse's reddish-orange hue is easily recognizable even by inexperienced observers.

Betelgeuse is an irregular variable with an average visual magnitude of 0.9 and a range of half a magnitude (a factor of 1½ times in brightess), although in recent years it has been observed as bright as zero magnitude and as faint as magnitude 1.5. At the same distance our Sun would appear as an undistinguished 11th magnitude star — some 10,000 times fainter. In near-infrared light Betelgeuse is the brightest of the naked eye stars, with an intensity over 100 times greater than the light of Earth's daytime sky. At these wavelengths, astronomers routinely observe the star with large telescopes in broad daylight during the summer months. On clear winter nights the spectrum can be recorded with large telescopes and modern detectors in a matter of seconds — quite a luxury in a science where light is usually such a precious commodity!

Betelgeuse is also among the few stars whose apparent angular diameter is large enough to be measured with an interferometer, an instrument that makes use of the wave nature of light to resolve extremely small angles. In 1920 Francis Pease measured its diameter at ⅟₂₀ second of arc — an angle equal to the size of a quarter at a distance of 50 miles. If Betelgeuse were placed at the center of the solar system its surface would extend almost to the orbit of Jupiter and the Earth would lie well inside the star, about one third of the way from the center to the surface. Recent measurements show that the outer layers of the star swell and contract by one third of the radius — between 300 and 450 million miles — over a period of several years.

Betelgeuse's brilliance — along with its resolvability — makes it a rich source of information about the nature of stellar structure and evolution. In recent years a wealth of data on its brightness, composition, size, and the motions of the gases on and above its surface have been collected with a wide array of spectrographs, ultraviolet and infrared photocells, interferometers, and other instruments stationed on Earth and in satellites above the atmosphere. By piecing this information together, astronomers have developed a fairly complete working model of the star — a model that now guides much of the current research work on stars cooler than the Sun. Before we take a closer look at some of the interesting recent discoveries and hypotheses about the star, let's first acquaint ourselves with a few of the well-established facts about its evolutionary state and internal structure.

Orion is a region of very active star formation, containing within its boundaries several clusters of young stars and their associated nebulae and dust clouds. Most of the bright stars of the constellation are probably less than 10 million years old, to judge from the expansion of the gas clouds in the region. A few may be as young as 2½ million years — relative newcomers to the Sun's part of the Galaxy. Of these, Betelgeuse alone has evolved into a red supergiant, a sign that it is one of the most massive stars in the area. Like a spendthrift, it is burning its fuel (mass) so quickly that it is already near the end of its brief life. If the Sun's evolution is represented by a three-hour timespan, Betelgeuse's lifetime as a *bright* star corresponds to only a single second.

We know the approximate makeup of Betelgeuse's internal structure from computer calculations. A dense core of carbon and oxygen lies at the center, which packs several tenths of a solar mass into a volume not much larger than that of Earth. One cubic inch of this material contains nearly a ton of mass. The core temperature of 100 million degrees Kelvin generates enough pressure to support the enormous weight of the star — but not enough to sustain nuclear reactions between the constituent carbon and oxygen nuclei. The core is surrounded by a shell of helium several thousands of miles thick. The vast bulk of the star, however, is a cool, extremely tenuous hydrogen envelope some 1,000 suns in diameter. If Betelgeuse were the size of a large beach ball, the core would fit on a pinpoint at the center.

Betelgeuse's energy comes from nuclear fusion reactions in two thin shells, one on the surface of the carbon-oxygen core and the second in a thin layer at the base of the hydrogen envelope. These reactions are burning their way outward through the star at the snail-like pace of a half-meter per year, consuming the lighter material of the zone above and leaving behind the heavier material of the zone below. In the helium-burning shell three hydrogen nuclei fuse to form carbon, which in turn fuses with helium to form oxygen. Most of the star's luminosity originates in the outer hydrogen-burning shell, where four protons (hydrogen nuclei) are fused into a helium nucleus. The reactions in both shells release enormous amounts of energy by transforming mass into intense gamma-ray radiation and heat according to Einstein's celebrated equation, $E=mc^2$. A typical gamma-ray photon then embarks on a long outward journey through the star, degrading in energy countless times until it finally emerges from the surface of the star in the form of infrared light.

Hot spots — sometimes called helium flashes — develop on the surface of the carbon-oxygen core due to instabilities in the thermal energy balance of the material. Energetic flashes can send bubbles of helium up with such speed that they tear through the hydrogen-burning shell, releasing plumes of gas rich in heavy elements into the hydrogen envelope. In the hottest flashes, carbon and oxygen may burn to produce other heavy nuclei such as silicon and magnesium, while other processes can build small amounts of rare elements such as barium and strontium. Thus, the intense nuclear fire within Betelgeuse is thought to be a furnace for advanced nucleosynthesis and heavy-element formation, in which virtually all the elements found in the Earth's crust are built up from carbon and oxygen. There are good reasons for believing that the bulk of the material of our familiar surroundings on Earth was formed in the cores of ancient red supergiants. As we shall see shortly, much of this material is returned to the interstellar medium for use by a later generation of stars.

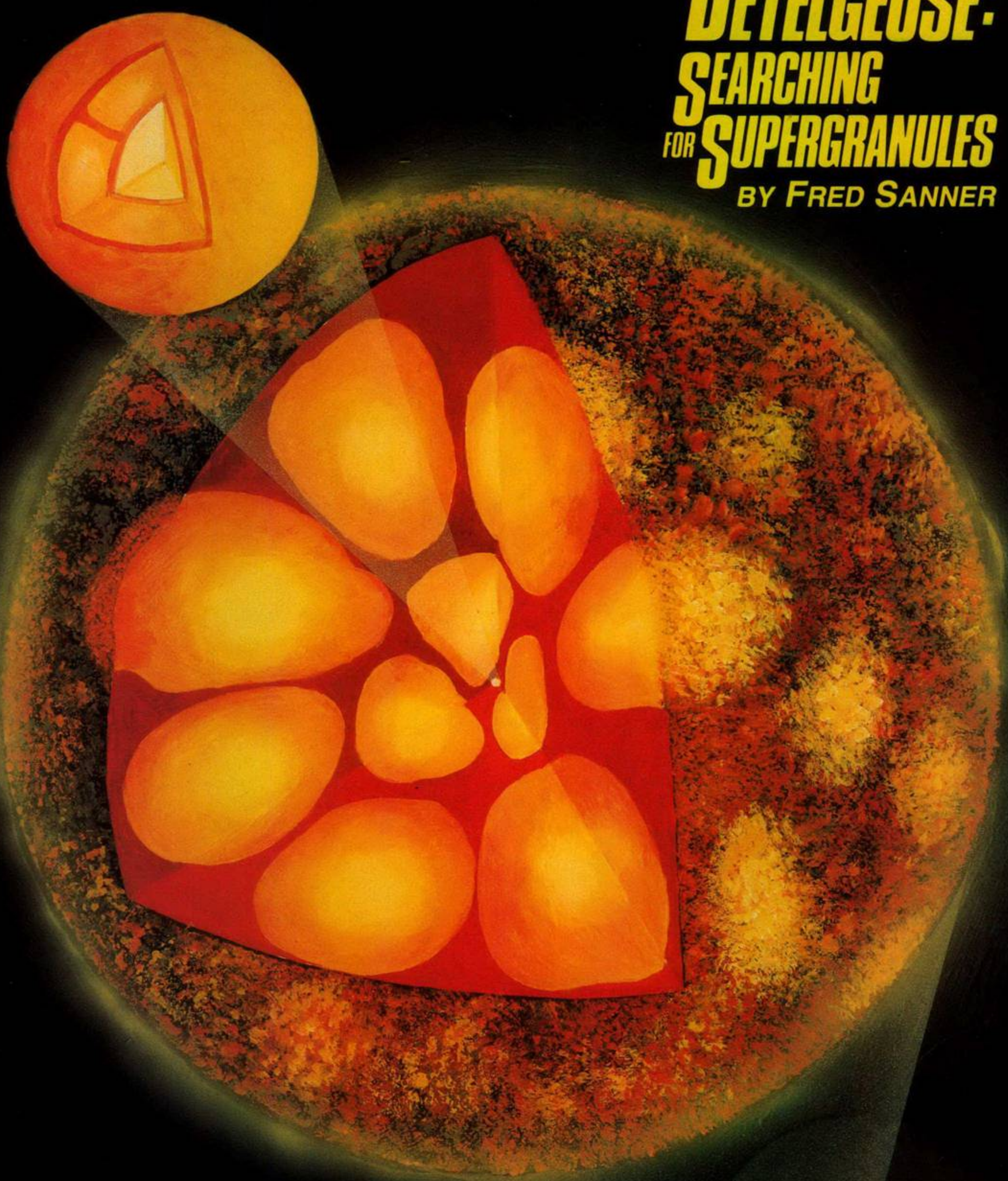
The course of Betelgeuse's evolution as a red giant is closely tied to the core-shell structure of its interior. As the inner shell burns through the helium zone, adding mass to the carbon core,

PHYSICAL PROPERTIES OF BETELGEUSE

Spectral Type	M2 Iab
Variability Class	Irregular
Visual Magnitude	0.4 to 1.3
Absolute Visual Magnitude	-5.9
Luminosity	10,000 suns
Distance	650 light-years
Diameter	350 to 500 solar diameters
Apparent Angular Diameter	0.016" to 0.023"
Central Temperature	100,000,000° K
Surface Temperature	3,200° K
Chromospheric Temperature	4,000° K
Circumstellar Temperature	300° to 1,000° K
Mass	16 solar masses
Mean Density	⅟₁₀ ₀₀₀ atmosphere
Mean Loss Rate	10^{-7} to 10^{-5} solar masses/year
Escape Velocity (at surface)	80 km/second
Mass Loss Velocity	8 km/second

BETELGEUSE: SEARCHING FOR SUPERGRANULES

BY FRED SANNER



Inside Betelgeuse is a complex mechanism at work: at upper left, the core is a dense collection of carbon and oxygen not much bigger than Earth; most of the star itself is a cool, tenuous hydrogen envelope extending outward some 1,000 solar diameters. Nuclear fusion occurs at two places: on the surface of the carbon/oxygen core and at the base of the hydrogen envelope. The inside of the star is composed of a vast congregation of convection cells called *supergranules*, which rise up and fall back down over a period of several months. At lower right is the star's circumstellar shell of cool gas, which reaches 100 billion miles into space. Artwork by Barbara Ericksen.

the core actually *shrinks* in size because there is no source of nuclear energy inside to support the additional weight. As the core shrinks, the hydrogen envelope becomes extremely distended and cool on the surface, taking on a reddish appearance. Some of the gravitational potential energy released by the shrinking core heats the star's interior and increases the total luminosity.

Betelgeuse's tenuous hydrogen envelope is in a state of turbulent convection throughout. Convection is a complex and poorly understood process, however, and no present hypothesis can tell us in detail how the gas moves inside the star. However, Martin Schwarzschild of Princeton University has given some convincing arguments — based on an analogy with the Sun's convective zone — that Betelgeuse's hydrogen envelope exists in the form of highly convective bubbles.

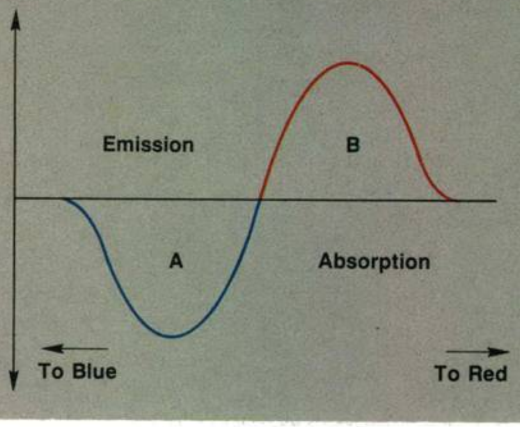
The surface of the Sun is covered by many little cells, or granules — each a small, self-contained bubble in which warm material rises to the center, spreads across the surface, and then sinks into the star at the intercell boundaries. High magnification photographs of the Sun's surface taken from balloons show the granulation to form a remarkable pattern of polygonal bubbles much like a honeycomb. The width of a typical solar granule is approximately 500 miles. At any instant the surface of the Sun may contain as many as 750,000 such cells, each of which has a lifetime of about four minutes.

What does the surface of Betelgeuse look like? Because its convective layer extends throughout most of the star, Betelgeuse's surface may contain as few as 30 to 100 giant cells, or *supergranules*, the largest ones capable of filling the orbit of Venus. Fewer than 15 to 50 supergranules of various temperatures and sizes may occupy the stellar disk as seen from one direction. Viewed close up, the star may well have a rather lumpy, uneven surface. These supergranules rise and fall in a leisurely fashion, taking several months to rise through the convective layer.

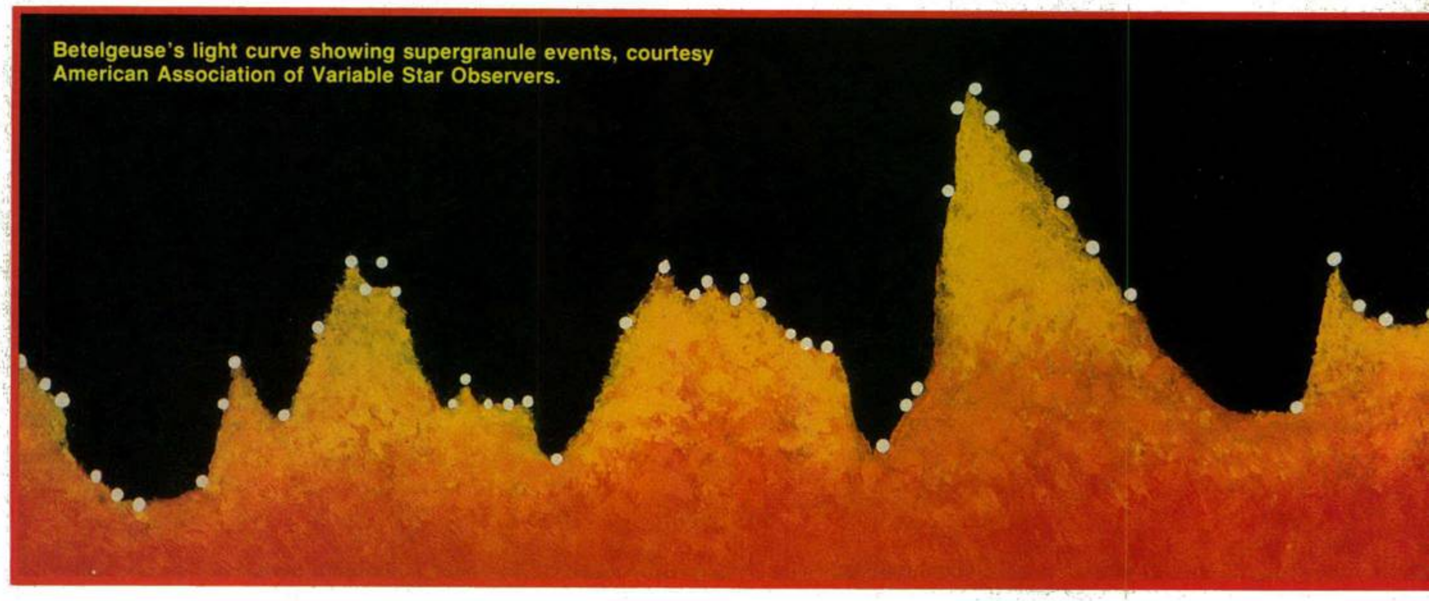
These hypothetical supergranules are believed to be the source of the star's irregular variations in brightness. Two observable effects are expected when a hot bubble reaches the surface. The star should brighten and appear less reddish because the supergranule is hotter than its surroundings, and the frequency of the star's light should slightly shift to the blue, an indication that the gases are moving in the direction of the observer. A portion of the light curve shown on pages 68 and 69, which covers the period 1945 to 1950 (a particularly active period of variability), shows a number of supergranule events in succession. In each event the star typically brightens over a period of about 50 days and then shows a slower decline lasting between 100 and 150 days. This suggests that after a bubble surfaces, the gases slow down as they cool and spread across the surface. Spectroscopic observations show irregular variations in the radial velocity of the surface by about eight kilometers per second. A bubble traveling at this speed for four months can rise 240 million km (one third of the star's radius) out of the convective envelope. Unfortunately, there are few *coordinated* observations of both brightness and velocity variations to document a supergranule event. Searching for supergranules on Betelgeuse has become an active area of research for astronomers interested in red giant stars.

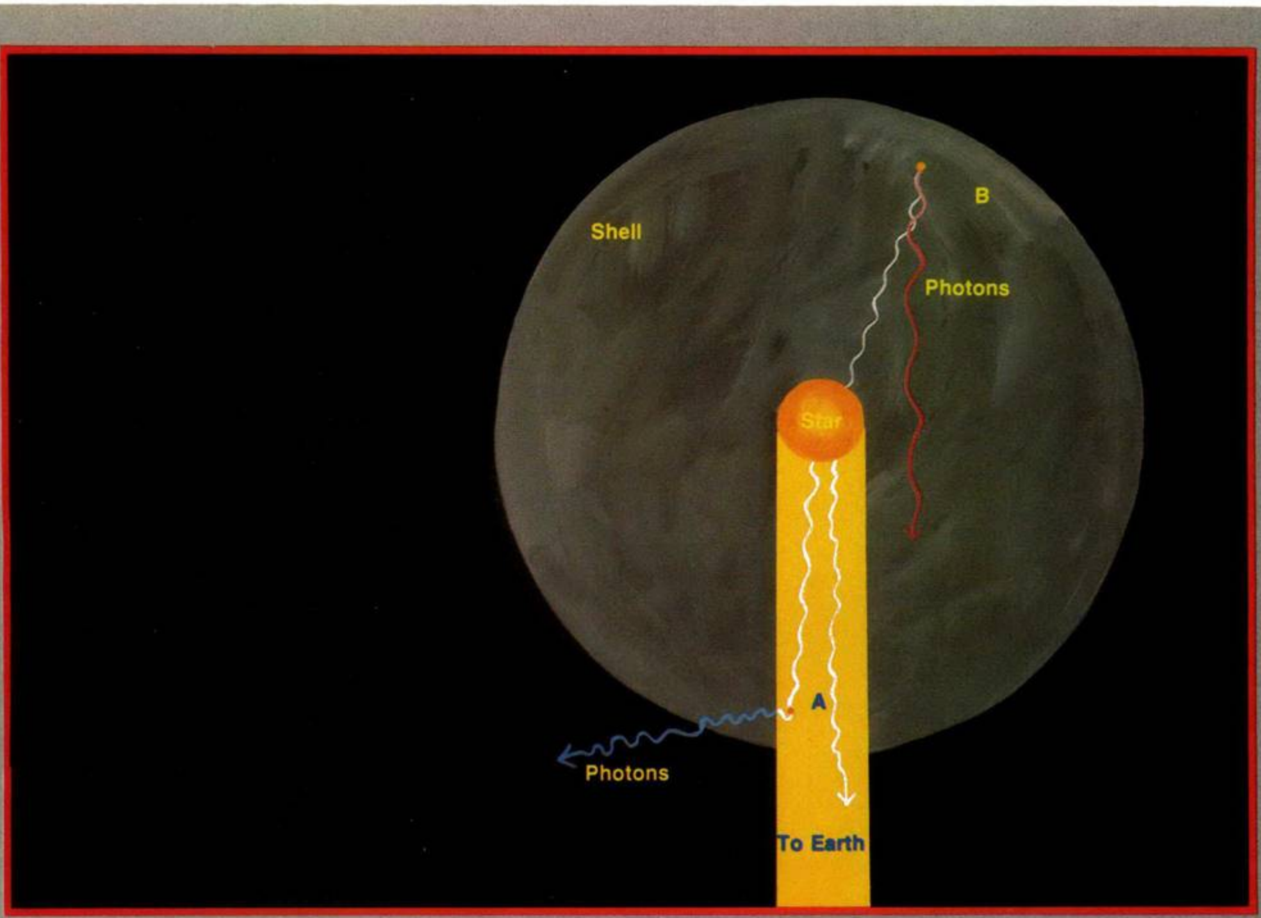
P Cygni Profiles

When a shell atom scatters light, it imparts a small Doppler shift to the frequency of the light waves, which depends on local velocity of the envelope. A distant observer studying the scattered light with a spectrograph can therefore sort out the motions of the gas. For example, light scattered from the back or receding half of the envelope (region B) is shifted slightly to the red, while light scattered out of the observer's line of sight (region A) by material between him and the star appears as a blue-shifted absorption trough. The composite profile of star and envelope — called a *P Cygni profile* after the shell star in which it was first observed — is the unique signature of an expanding shell above the photosphere. By measuring the P Cygni features of lines of different elements, Betelgeuse is estimated to be losing one millionth of a solar mass per year — the equivalent of one trillion tons each second!



In 1973 astronomers at Kitt Peak attempted to "see" a supergranule event directly with a speckle interferometer. A star's

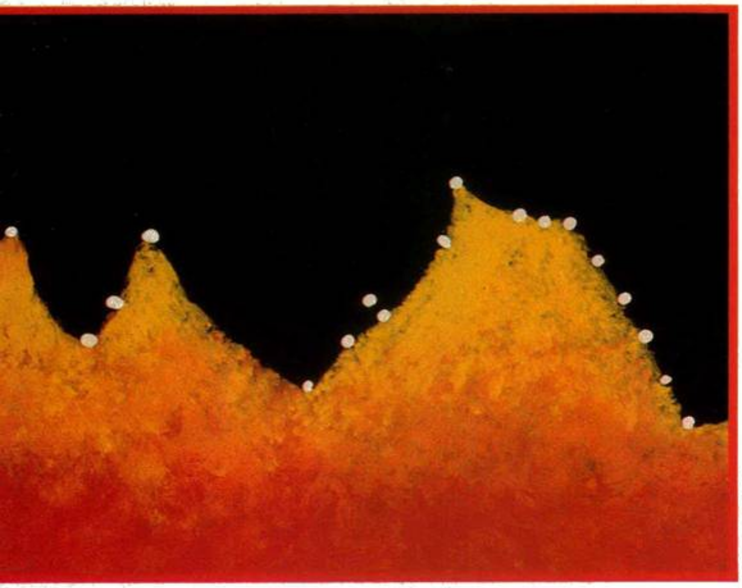

Betelgeuse's light curve showing supergranule events, courtesy American Association of Variable Star Observers.



Barbara Ericksen

instantaneous image, as transmitted through the temperature and density irregularities in the Earth's atmosphere, is made up of hundreds of separate images of the star called *speckles*. The technique of speckle interferometry mathematically recombines the best of these to reconstruct the brightness distribution on a star's disk. A large supergranule on Betelgeuse — 1/100 arc-second in diameter — might just be detectable on an individual speckle with the 3.8-meter aperture of the Mayall telescope on Kitt Peak.

The Kitt Peak image of Betelgeuse *did* suggest a faint mottling of the brightness across the face of the star, but unfortunately the resolution was not quite sufficient to give a clear picture of a supergranule. Glimpsing a supergranule may require a larger telescope and just the right moment — a bright peak in the light curve — to catch one as it emerges from the envelope.

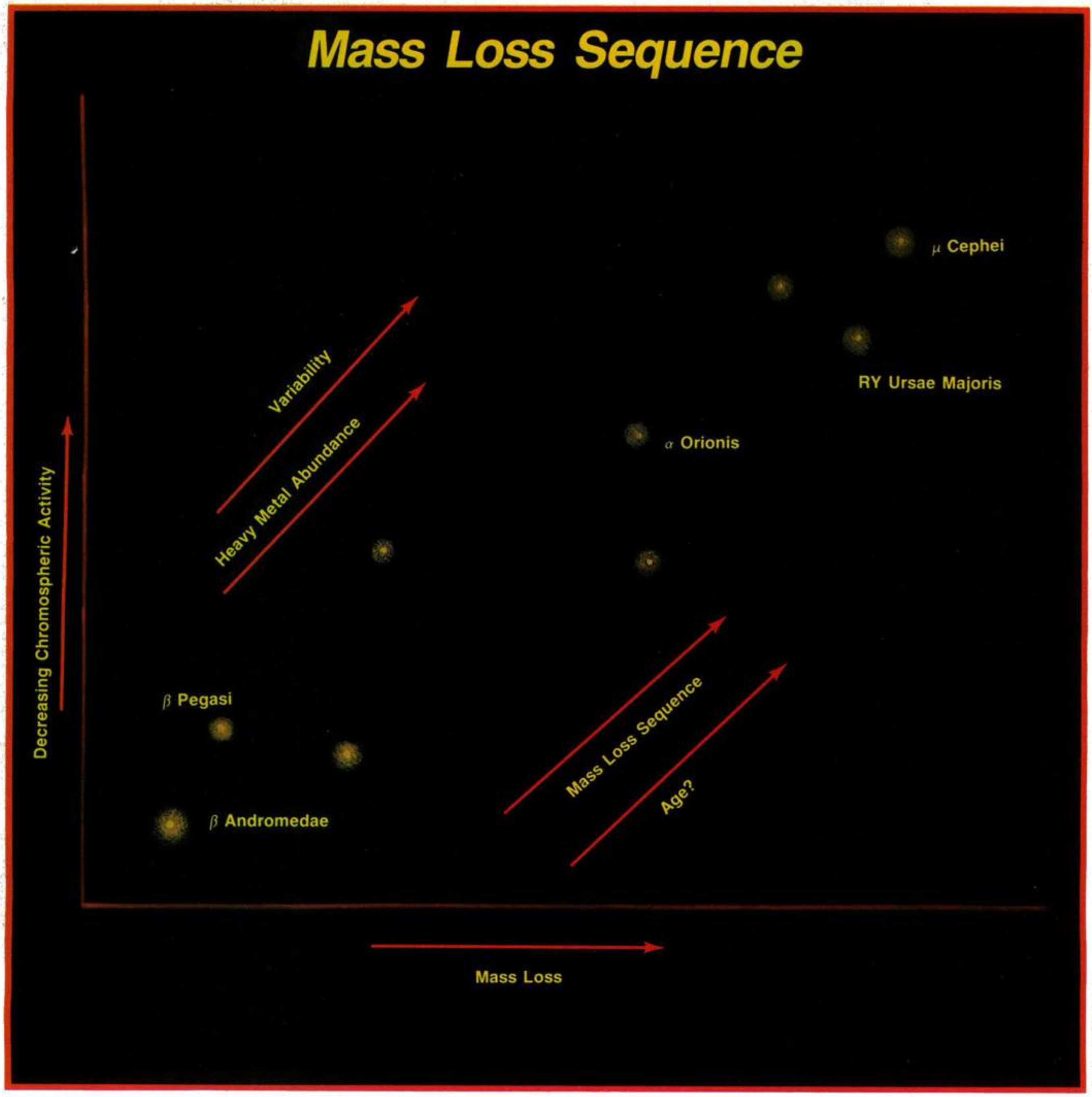


Jane Borth

Above the photosphere is the chromosphere — a hot, very low-density region of the atmosphere — in which the temperature *rises* as distance from the star increases. The chromosphere may be very much like a collection of "flames" on the stellar surface; its spectrum consists chiefly of emission lines of abundant metal atoms — most notably those of ionized calcium, the classic indicator of chromospheric activity on the Sun. Studying red supergiants that are also members of eclipsing binary systems, such as VV Cephei, has permitted astronomers to observe huge inhomogeneities in red giant chromospheres during eclipses. These are structures of gas which rise to great heights above the photosphere, probably very much like prominences on the Sun. Although there are no direct means of observing such prominences in single stars like Betelgeuse, evidence from other sources, such as polarization measurements, lends support to this kind of picture for Betelgeuse as well.

Extending far above the chromosphere is an enormous envelope of cool circumstellar gas, reaching 100 billion miles or more into space. Using spectroscopic observations, astronomers inferred the existence of the envelope nearly 50 years ago, but it was not until very recently that advances in the sensitivity of photoelectric detectors have allowed astronomers to see the shell directly against the sky. The gas is slowly welling out from the star at a speed of about eight km per second, gradually cooling off as it moves outward from the temperature of the chromosphere to the cooler interstellar medium.

The envelope is transparent to the star's light except at the characteristic frequencies of abundant atoms such as calcium, potassium, and sodium. When a shell atom scatters light, it imparts a small Doppler shift to the frequency depending on the local velocity of the envelope. By studying the scattered light



Barbara Ericksen

with a spectrograph, a distant observer can therefore sort out the motions of the gas. In this way Betelgeuse is estimated to be losing roughly one millionth of a solar mass per year — a trillion tons every second.

The envelope's scattered light is extremely difficult to detect against light scattered in the Earth's own atmosphere. But by placing an occulting disk inside the telescope to block out the direct image of the star — coupled with a filter carefully tuned to the light of the potassium atoms — photographs of the region of sky around Betelgeuse reveal a vast extended glow, more or less spherically distributed around the star. Measurements of the shell made at remote observatory sites where the night sky is exceptionally dark show the potassium gas to 500 stellar radii, almost a minute of arc in the sky. Observations made from above the atmosphere with the Space Telescope may reveal an envelope the apparent extent of the Full Moon — some 15,000 radii.

How is the gas lifted so gently against the gravitational pull of the star? A possible explanation for the mass flow emerged in 1971. Infrared observations of Betelgeuse and several other red giants revealed an excess of radiation from the stars in the form of a broad emission feature at 10 microns wavelength. The feature has become known as the "silicate bump" after its laboratory identification with warm silicate dust — fine particles of glass and probably other common minerals.

Betelgeuse's upper atmosphere is evidently a favorable environment for the condensation and growth of microscopic dust particles. This is largely because the usual mechanism of grain destruction in stars, an intense ultraviolet radiation field, is not present in the relatively cool atmospheres of red giants. Unlike gas, the dust is a very good absorber of light over a wide range of wavelengths. When a dust particle grows beyond a critical size, about $\frac{1}{10\,000}$ inch, the pressure of Betelgeuse's light exceeds the star's gravitational pull and the grain is pushed outward. Collisions between the dust grains and the gas drives the gas away as well, lifting the entire outer atmosphere away from the star.

This explanation predicts a number of the observed properties of the mass loss fairly well. The forces of gravity, radiation pressure, and gas drag tend to balance each other to produce a flow with uniform speed over great distances. (The speed depends on the sizes of the grains, their ability to absorb light, and the relative amounts of gas and dust.) The hypothesis also predicts variations on the mass loss rate from one star to another due to differences in the amounts of granular material in each star. The coolest and most luminous stars like Betelgeuse should produce and expel the most dust and gas, and this is exactly what is observed.

Astronomers have recently discovered an interesting relationship between mass loss and chromospheric activity in red giants. Stars with strong chromospheric emission lines, for example Beta Andromedae, tend to show little or no signs of dust, while stars like Mu Cephei — a red giant intrinsically more luminous than Betelgeuse and of about the same surface temperature — have strong infrared excesses and little or no chromosphere. Betelgeuse and most other red giants fall somewhere between these extremes, along what appears to be a sequence of increasing mass loss, greater variability, and weakening chromospheric activity. Many of the stars at the high-variability end of this "Mass Loss Sequence" also show photospheric overabundances of the heavy elements produced in the advanced stages of nuclear burning, such as barium, strontium, and carbon. Betelgeuse holds a fairly central position on the sequence, showing some signs of just about all of these processes.

According to this sequence the red giants seem to be faced with a choice: either they use the excess convective energy of their photospheres to heat a chromosphere, or they transport matter into space. If a star does one process well, it is usually at the expense of the other.

Some astronomers feel that the mass loss sequence is essentially an ordering of stars by their atmospheric dust content. In the stars with dusty atmospheres the grains quench the chromospheric flames by radiating (cooling) in the infrared and simultaneously driving the mass loss. But others argue that something else must be involved in the choice between a chromosphere and mass loss. The pair of stars RY Ursae Majoris and Beta Pegasi illustrate this argument. Both have similar temperatures and luminosities and so should have similar concentrations of dust in their atmospheres. But RY Ursae Majoris is a variable with a dusty envelope, while Beta Pegasi has an active chromosphere and no signs of dust.

This "something else" may be a magnetic field. In the Sun, the calcium emission lines are closely linked to the magnetic field strength, and theoretical arguments show that magnetic fields can set up oscillating wave motions in a gas that have the effect of rapidly stirring it up, producing heat and emission lines. In addition, many of the large-scale structures of the Sun's outer atmosphere — the spicules, prominences, and coronal streamers — display the unmistakable stamp of the magnetic field on their shapes and motions. It is possible that the magnetic fields slow down mass loss by redirecting jets of ionized gas back to the surface of the star along closed field lines, much as seems to happen in the solar prominences. Beneath the photosphere, tubes of magnetic flux may tie down the convective motions of a stellar envelope. In a star like Betelgeuse, this would restrict or eliminate the supergranule motions and the variability.

Although the importance of magnetic fields has been gaining some momentum in recent years, these ideas are still very speculative and are likely to remain so for a long time. As theoreticians well know, gas motions in the presence of magnetic fields are notoriously difficult to understand theoretically, and any good observer will testify that the field strengths likely to play a role in a star like Betelgeuse are far too weak to measure with present observing tools. Still, many astronomers are hopeful that further study of the solar atmosphere can give some clues about the connections among convection, chromospheric activity, and mass loss that can be applied — at least in broad principle — to the atmospheres of red giants and supergiants.

What lies in store for Betelgeuse? Betelgeuse's future evolution is a matter of speculation, but there is little disagreement that the detailed course of its evolution to a large extent depends on how fast it is losing mass. Several possible courses of evolution may lie ahead. If the rate of mass loss is sufficiently great (10^{-5} or more solar masses per year), the entire hydrogen envelope will evaporate in less than two million years, leaving behind only the remnant core — a white dwarf. If the mass loss rate is moderate (between 10^{-6} and 10^{-7} solar masses per year, the pressure of the hydrogen envelope on the core will be maintained for a much longer time. Contraction of the core will then continue to raise the central pressure and temperature until carbon and oxygen begin to burn at the center. This additional source of energy may be sufficient to blow the outer layers of the star away in a single dramatic event — forming a planetary nebula.

Polarization

If a common polarizing filter is placed between Betelgeuse and a detector, only that light polarized along the orientation of the filter is measured — in much the same way that sunglasses reduce the glare of light scattered from a road surface. Using this technique, the light from Betelgeuse is found to be about 10 percent polarized: the star is slightly brighter with the filter placed in one orientation than in all others. Both the orientation of brightest light and the percentage amount of polarization vary from month to month with about the same timescale as the brightness variations.

Polarization — a structured pattern of wave motion — most commonly occurs when light is scattered from a structure which is *asymmetric* about the line of sight, or if the source of illumination itself lacks this symmetry. In the case of Betelgeuse, the polarization might arise when light from a hot convective cell is scattered from a dense prominence higher in the atmosphere. But to account for the relatively large amount of polarization, the prominence must be extremely large and dense compared to those on the Sun. Thus, as the polarizing filter is rotated, first one, then another prominence comes into view and then disappears as its scattered light is no longer passed by the filter. Over a period of six months, as the relative orientations of supergranules and prominences change, the star's net polarization varies in magnitude and direction.

At very low mass loss rates (less than 10^{-8} solar masses per year), the central pressure is never relieved, and the temperature will continue to increase unchecked. A possible result is runaway nuclear burning and ultimately a major explosion — a supernova. If Betelgeuse behaves like other supernovae in the solar neighborhood, the explosion may be preceded by a period of enhanced variability, followed by a one or two day rise to maximum brightness. From Earth, the supernova would appear as a star of magnitude -13, brighter than the Full Moon and easily capable of casting shadows. No one knows if or when such an explosion is likely to occur.

Whatever happens, Betelgeuse is destined to shed the bulk of its mass before it dies, but the mechanisms by which it will do so differ in violence and timescale. Our present knowledge is still far too imperfect to tell us how well the safety valve of mass loss will moderate the death of the star.

A great deal of work remains to be done to answer some of the basic questions about how stars grow old and die, and in particular to gain a better understanding of how the complex interplay of mass loss, chromospheric activity, and the supergranules affect a star's evolution. Fortunately for us, nature has seen fit to place Betelgeuse near enough so that we can take a unique, close-up look at the surface of an aging star — a look that can help us better understand what lies in store for our own Sun.

Fred Sanner worked on mass loss in red giant stars for his Ph.D. in astronomy from the University of Chicago, and has since served as a resident astronomer at Kitt Peak and McDonald Observatories. He is currently a member of the technical staff at Hughes Aircraft Co. in Fullerton, California.

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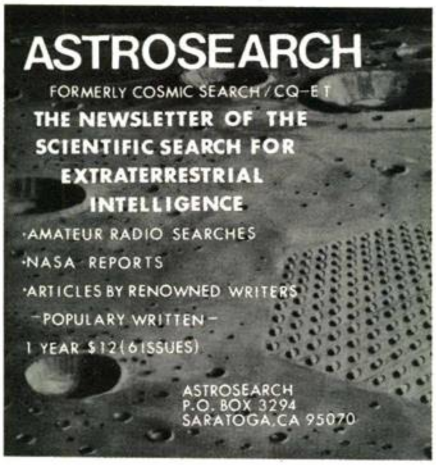

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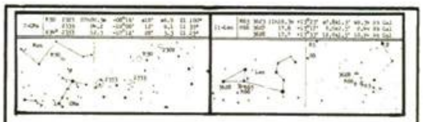

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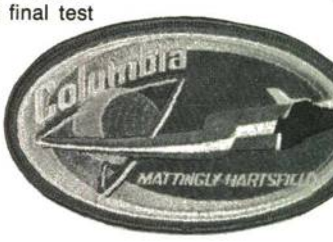

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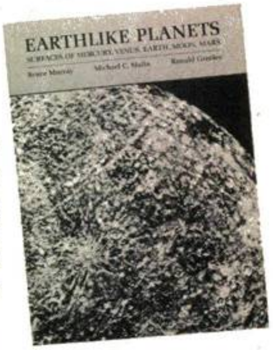

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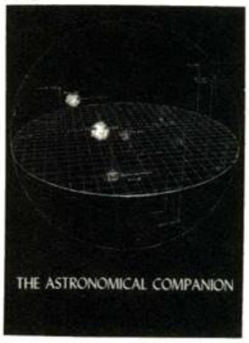

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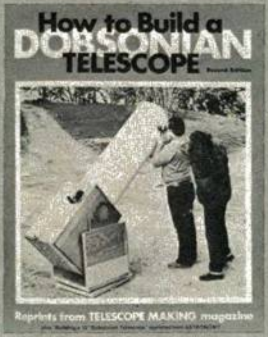

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how to make your newtonian telescope somewhat more portable

The summer observing season is coming up. Predictably thousands of avid observers will stuff spouse, three kids, the tent, the Weber, the bedrolls, the freeze-dried food, the assorted rec-gear in the family Honda and head for the hills. But don't forget the telescope. . . .

The TELESCOPE? "That THING?" says the spouse. "It's too big." And bulky, and too heavy, you silently agree, but not giving any outward sign that you agree. The youngest snivels that you're not bringing the Atari. "No electricity, no Pac-Man," you say. Dark skies, you think, mountain-clear dark skies. "Oh, Mommy," says the oldest, trying to be diplomatic, but forcing the point anyhow, "If the telescope comes, where will the duck boat go?" Good point, kid. But this year the duck boat stays home.

Remember last year? The telescope stayed home. The duck boat came with. But the lake was off-limits to duck boats, so the duck boat never got used, and for three glorious nights you sat under stars so big and bright you could almost reach out and touch. With no telescope.

Not that that was so bad in and of itself — the sky was splendid to see. The Milky Way glowed, the star clusters along it shone visibly to the naked eye, and you traced out the faint constellations that the citizens of Metropolis never see through the smog and the dust and the glare of city lights. It made the trip worthwhile.

Still, the telescope would have been nice. Just to look. And maybe see the Cygnus Loop. . . .

But compromise is the essence of harmonious family life. There are strong pressures to give up the telescope entirely. If only it were half as big. HALF AS BIG! Now there's an idea.

The telescope has a tube assembly and a mounting. The tube weighs in at about 20 pounds and the mounting at about 40. The tube is the important part. And the tube, while not small, is at least a cylinder (and it's empty, too, so you could stuff it with clean clothes for the trip up the mountain). But the mount is the awfulest thing ever invented by man. Why not take just the tube and leave the mounting behind? Or is that too radical?

Well, you'd have to find some other way of supporting and pointing the telescope. Nah, that'd never work. Or would it? You could stick it on one of those Dobsonian mounts. Nice and low, light and cheap. Good enough for poking around the sky. Maybe take the pieces flat, hide them in the bottom of the trunk, then nail them together when you get there. An Instant Telescope!

The Solution to the Problem

There are no easy answers. But sometimes there are unexpectedly simple solutions to difficult problems. There is no reason why your telescope should be used only with the mounting it came on. A mounting is, after all, nothing more than a gadget to hold and point the telescope. If one mounting is too bulky to lug around, then put the telescope on a smaller one. When you don't mind lugging, use the one; when you do, use the other.

The mounting your telescope came with was probably an equatorial. It tracks (and needs electricity!), has setting circles, rotating tube rings, and raises the telescope about three feet off the ground. How about an alternative that responds to the gentle push of a finger, sits low and close to the ground (observe sitting down!), and lets you star-hop with ease?

You could even build a few of these little alternatives and leave them places you go often. Leave one at Grandma's — when you visit, take only the telescope. Leave one at the summer cottage — when you vacation, take only the telescope. You could even keep one at home for deep-sky observing sessions or whenever you don't feel like polar alignment. Use the original mount for astrophotography, or for high-power planetary work, or at star parties to keep things in the field for long periods of time.

Implementing That Solution

Well, it's easy to say you're going to put your scope on a Dobsonian mount for easy portability. But let's see you really do something about it.

What's to be done? First, you need two vital statistics about the telescope. They are:

(1) The diameter of the tube.

(2) The distance from the rear of the tube to its balance point.

The diameter of the tube is easy; just measure it with a ruler.

To find the balance point, remove the tube from the mounting. Put your favorite eyepiece in the eyepiece holder. Find a broom handle or some other obliging bit of round material. Put it on the floor on a soft rug, then place the telescope across it at right angles. One end of the telescope will rest on the rug; the other end will be raised. Slide the broomstick toward the end that's resting on the rug; at some point, the telescope will abruptly teeter over so it rests on the other end. Simply measure the distance from the back end of the tube to the "teeter point." Armed with these two numbers, you may now proceed to design your custom telescope mounting.

All Dobsonian mounts are divided into three parts. The box holds the tube; the rocker holds the box; and the ground board holds the rocker. The box has side bearings, one on each side, and they're what the telescope moves up and down on. The side boards of the rocker support the side bearing attached to the box. The bottom of the rocker is covered with smooth kitchen-table-top plastic which turns on slippery frying-pan-bottom plastic on the ground board. The ground board sits on the ground.

The vital statistics you have just measured serve two purposes. The first is to assure that the telescope fits into the box. The second is to assure that the box with the telescope in it fits into the rocker. You must (1) make the box big enough and (2) the rocker tall enough and (3) wide enough to hold the telescope and the box. These three dimensions you cannot fudge. Other dimensions are not critical.

Figuring Some Dimensions

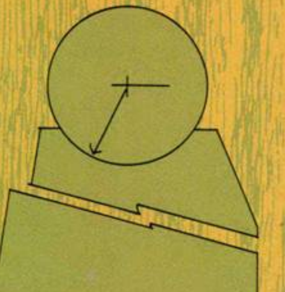
Just to make things easy, we'll do an example for you. Suppose you have a sweet little 6-inch f/5 RFT that's just yearning to accompany you to the campground. Its tube is 7½″ in diameter, and the balance point, with eyepiece, is 14″ from the rear end. Of course your telescope is likely to have different dimensions, so you'll have to figure out your own mount's dimensions. Okay?

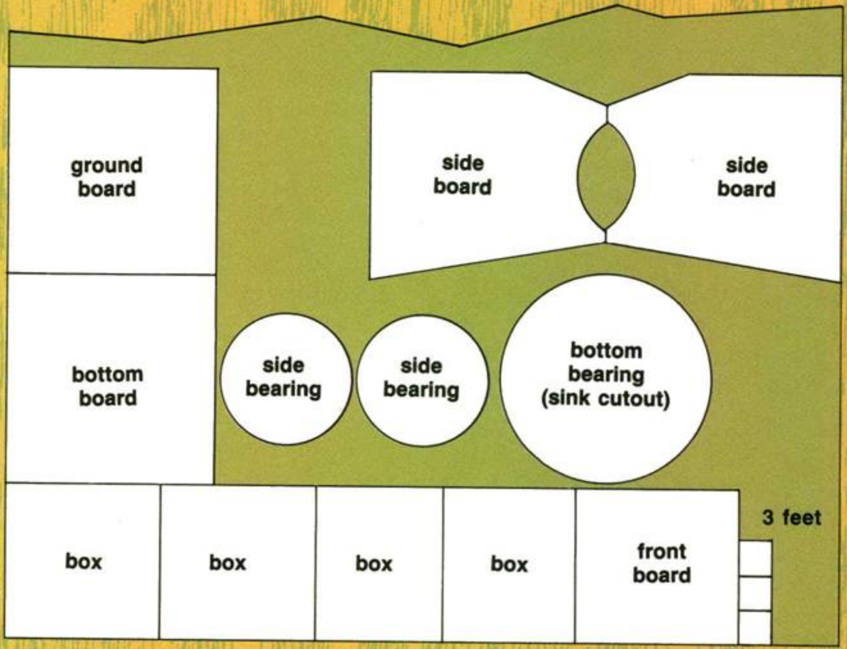
We'll build our new mounting from ¾″ plywood. We could use thinner plywood, say ½″ or even ⅜″ thick, but ¾″ is thick enough to insure excellent stability and is actually easier for a ham-handed carpenter to work with than the thinner stuff. You'll need less than a half sheet of plywood for any 6-inch, and a half sheet will suffice for most 10-inchers, too.

To fit the tube, the inside dimensions of the box must be 7½″ x 7½″. With ¾″ plywood, that means the outside dimension of the box is 9″ x 9″, the first unfudgeable dimension. To make the box, then, cut two 9″ x 9″ panels and two 7½″ x 9″ panels. We'll also need to cut two side bearings 7½″ in diameter — a dimension that is somewhat arbitrary. Those six pieces make up the box.

Now for the rocker. The telescope sticks 14″ beyond the balance point, but if you put it in a rocker 14″ high, the bottom corner of the tube would hit the bottom of the rocker whenever you pointed it away from straight up. So how tall should the rocker be? Well, remember the Pythagorean Theorem from high-school math? The distance we need is the hypoteneuse of a right triangle 14″ long and half of 7½″ wide. So square the sides, sum them, and take the square root. The answer is 14.431″ — but you might just check up on that!

What's it mean? The center of the side bearing must be at least 14.431″ above the bottom of the rocker. Just for safety's sake, we'll add another inch and round it off to get 15½″, the second dimension that we cannot fudge. The third is the inside width of the rocker. Since the outside of the box is 9″, if you allow ⅛″ clearance on each side, its width should be 9¼″.





Now we'll dimension the four pieces of the rocker: two side boards, one bottom board, and one front board. First the side board: the curved top fits against the side bearing with ⅛″ to spare, so we'll cut them to a radius of 3⅞″. We'll make the width of the top 8″ and the bottom 12″ — rather arbitrarily chosen numbers. Since the total height from the bottom of side board to the center of the side bearings is 15½″, draw that height directly onto the wood, swing a 3⅞″ radius, then cut out the resulting shape. Talking about it is trickier than doing it.

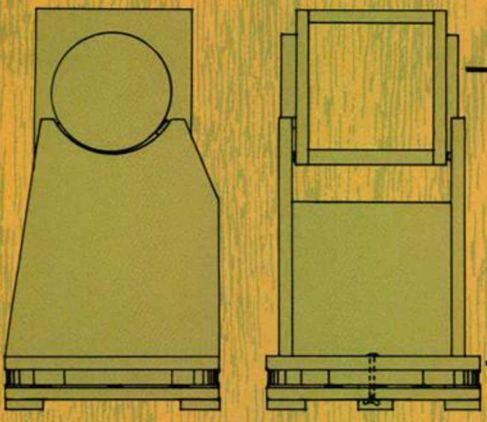
The bottom board has to be the width of the side board, or 12″, and since it's not fussy, we'll make it 12″ across also. Finally, the front board fits between the two side boards, so it must be 9¼″ wide. We'll make it 9″ tall, another non-critical dimension.

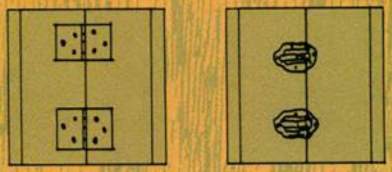
Next, there's the ground board — we'll make it 12″ x 12″ just like the bottom board. Finally you'll need a bottom bearing made from that famous plastic table-top material, Formica. A whole sheet of this stuff is expensive — about $30 — but there's a sneaky way out. When home centers make prefab kitchen cabinets, they cut a hole for the sink in the top of each cabinet. What happens to the holes? You guessed it — they sell them cheap. These holes, or "sink cutouts," are perfect for Dobsonian telescopes: a piece of Formica bonded to ¾″ thick particle board. You can get a sink cutout for about $2.50. Buy one. Cut a 12″ diameter circle from it.

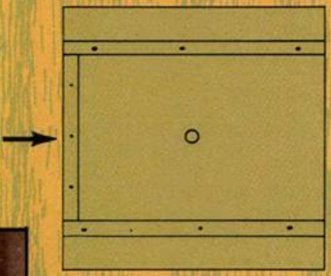
One, Two, Three — Go!

Okay, let's see what you've done so far. You've cut out 11 pieces of plywood, one circle of sink cutout, and have one lonely telescope. What's next?

A trip to the hardware store. Buy two small hinges, two suitcase clasps, 48″ of ¾″ wide Formica counter edging, a ⅜″ x 3″ carriage bolt and a ⅜″ wingnut, nails or woodscrews, wood glue, and some brads about ½″ long. Next, zip over to your local plastics store (this may be a problem if you don't have a plastics store

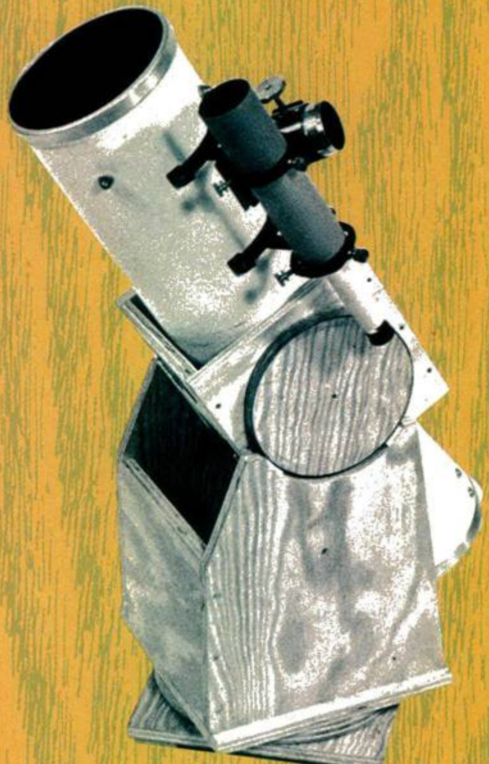






Thanks to Dennis Wilk and Rosemarie Kearns for playing model.

Who needs a workshop? Even the kitchen table makes a good-enough workbench, er. . . providing your spouse doesn't mind a little sawdust, glue, and maybe a few dents in the table.



in town. Look in the phone book business yellow pages under "plastics — rods, tubes, sheets") and buy some cutoffs — scrap pieces — of ⅛" thick Teflon plastic. You need about 12 square inches of the stuff, which should cost you about $1.50. Maybe they'll even *give* you this much because the paperwork involved in selling it to you will cost them more than that.

Now start putting things together. Assemble the box with wood glue and nails; or, if you take pride in doing things the right way, use woodscrews instead of nails. Glue the side bearings to the box and reinforce them with whatever fasteners you're using. Next, saw the box neatly in two, and install the hinges at the bottom and the clasps at the top to hold it together again. When you open the hinged box, put the tube in it, then close it. It should hold the tube snugly. Foam rubber pads will help hold the tube if the box is too big.

The rocker is next. Attach the side boards to the bottom board 9¼"(or whatever *your* dimension came out) apart. Drive the nails (or woodscrews) through the bottom board and into the side boards with the front board between them. Place the front board between them and nail it in place. The rocker is now a four-sided box — with a bottom, sides, and front.

Stack the ground board, the sink cutout circle, and the rocker squarely on top of one another, then drill a ⅜" hole dead center through all three layers. This is the hole for the ⅜" carriage bolt. Spread some glue on the particle-board side of the sink cutout and clamp it to the bottom of the rocker. Make sure the hole you just drilled is aligned with the hole in the rocker!

Finish the ground board by attaching three 2" x 2" feet cut from the leftover ¾" plywood to the bottom. Nail three pieces of Teflon plastic roughly 1½" x 2" to the other side about 5" from the center pivot hole with the brads. You can cut Teflon plastic with a sharp knife, a saw, or a chisel. Drive the heads of the brads below the surface of the plastic.

Finally, glue the Formica countertop edging to the edges of the side bearings. (If you couldn't find edging anywhere, a ¾" wide strip of thin aluminum or stainless steel will work just as well.) Nail four more small pieces of Teflon to the tops of the side boards with brads just as you did on the ground board, and two more pieces inside the side boards.

All Done! Enjoy

At this point you should realize that you are finished. Bolt the rocker to the ground board (wing nut up), put the telescope in the box, drop the box into the rocker, and you're ready to use the telescope. It should move very smoothly — the gentle push of your pinkie is all the force needed. Mess around until you have the telescope balanced right and the eyepiece sticking up at a comfortable angle for you. Paint the whole thing if you want to do things right, or just skip the paint if you're in a hurry.

Notice that there is nothing delicate about this mounting, and not much about it that you can hurt. Fill it with miscellaneous camping gear and tell the family it's a carrying box. Cram it into the trunk under the duck boat. Leave it or clones of it at Grandma's and the summer cottage and anywhere else you want to take the telescope. Then relax. This year, you can take it with you!

— Richard Berry

the backyard astronomer

canes venatici

Mercury

Right after sunset on the first few days of May, Mercury will be an inconspicuous object very low in the west-northwest. It will soon vanish from sight as it passes through inferior conjunction on the 12th, moving into the morning sky, where it will reach a relatively unfavorable western elongation on June 8th.

Venus

In early May, Venus will climb to its greatest elevation over the western horizon for this evening apparition. Greatest elongation comes on June 16th, but by then the planet will have begun to lose some of its height. Venus will continue to increase in brightness from its present magnitude of -3.6 (on the 1st) to a maximum of -4.1 in early July. Its disk will gain approximately 5″ of arc in size over the course of May, and its phase will shrink from about 70% lit on the first to a little over half-lit on the 31st.

On the evening of the 8th, Venus will lie about 10′ of arc to the south of the 4.9 magnitude star 139 Tauri — an easy pairing for low- to medium-power eyepieces. The Moon, a few days past New, will pass to the south of Venus on the evening of the 15th. A very low-power eyepiece will place them in the same field of view, making a pretty sight.

Mars

All month, Mars will be too close to the Sun to be seen.

Asteroids

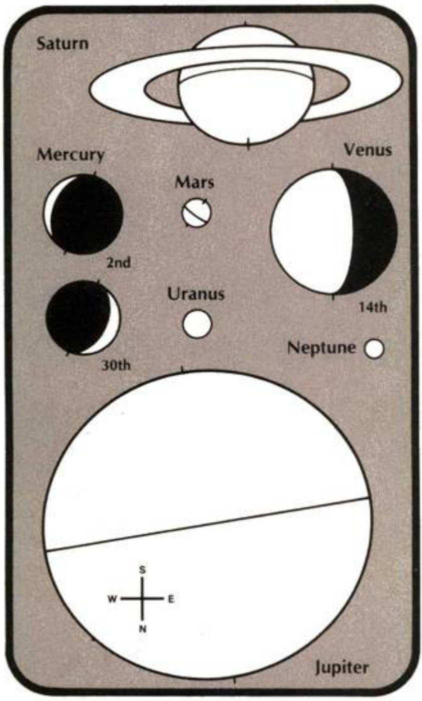
Ceres (magnitude 8.5) lies in eastern Capricornus. Its positions:

9th: 21h 51m 00s, −20° 53.3′
19th: 21h 59m 45s, −20° 49.5′

Ceres rises around 3 a.m. local daylight time in the middle of the month.

Two weeks before the lunar eclipse last December, a partial solar eclipse was visible over Europe and western Asia. Janos Kelemen of Budapest took this photo showing the Sun, sunspots, and an irregular lunar limb with a 20-cm f/15 refractor on 200 ASA film. It wins the "Best Astro-Photo" award for May.

Pallas (9.6) is moving retrograde near the Sagitta/Vulpecula border, where it will occult (maximum duration: 46 seconds) the 4.8 magnitude star 1 Vulpeculae between 4:42 and 4:59 UT on the 29th. Only those living in the southernmost states of the U.S. will see an occultation; those to the north will see a close conjunction. Its positions:



9th: 19h 20m 14s, +18° 45.1′
19th: 19h 18m 56s, +20° 09.4′

Pallas rises around 10 p.m. local daylight time on the 15th.

Juno (10.3) lies in western Pisces. Its positions:

9th: 23h 40m 12s, +0° 45.3′
19th: 23h 56m 48s, +2° 05.1′

Juno rises about 3 a.m. local daylight time at mid-month.

Vesta (8.3) is in northeastern Cetus. Its positions:

9th: 2h 18m 27s, +8° 36.7′
19th: 2h 35m 29s, +10° 02.9′

Vesta rises about 5:30 a.m. local daylight time on the 15th.

To facilitate plotting their positions on a star atlas, all asteroid coordinates are for the epoch 2000.

Jupiter

Jupiter comes to opposition on May 27th. See Gazer's Gazette on page 51 for details.

Saturn

At opposition on the 21st of April, Saturn is also featured in Gazer's Gazette this month.

Uranus

Uranus reaches opposition at 1h UT on the 29th. It is very close to Jupiter, which passed Uranus on the 16th at 13h UT while moving retrograde. At the time of conjunction, Jupiter will lie about 50′ of arc north of Uranus. Scanning near Jupiter with a low-power eyepiece will quickly reveal this planet — it has a disk 3.8″ of arc across and is at 5.8 magnitude.

Neptune

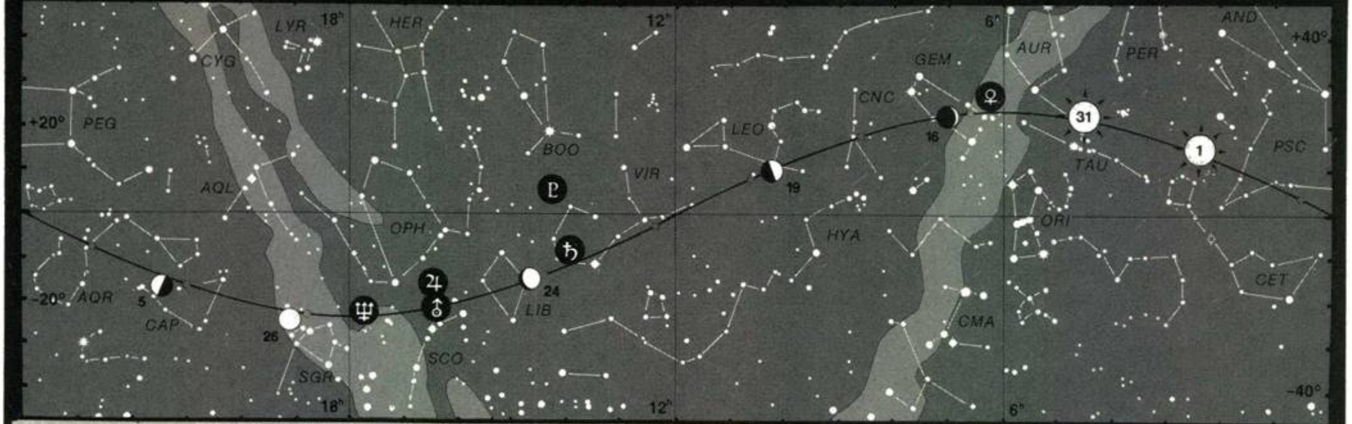
Neptune will rise around 11 p.m. local daylight time in mid-May. Located in Sagittarius about 2° to the northwest of M-20, the Trifid Nebula, Neptune is moving westward (retrograde). The planet is easy to identify with at least a medium-power eyepiece by its 2.5″ of arc, 7.7 magnitude disk.

Meteors

May's best annually recurring meteor shower is the Eta (η) Aquarid, a moderately strong stream whose radiant is near its namesake star. These meteors are derived from Comet Halley (as are October's Orionids) and tend to be very fast, since Earth is plowing almost straight into them. They also tend to leave long trails. Their peak activity will come on May 5th at around 11h UT, but the Moon is near Last

For information on naked-eye sky viewing, including planets, constellations, and mythology, see **Eye on the Sky**.

planetary data may 1983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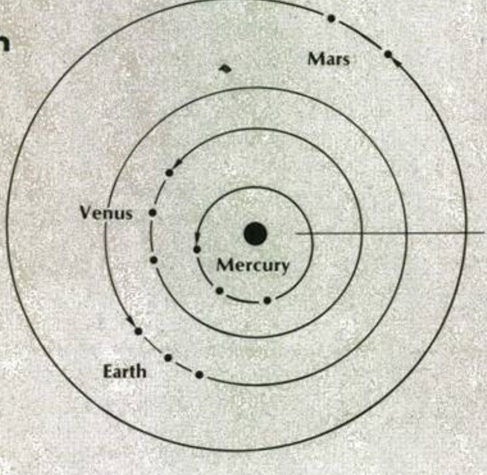
inner solar system


Mars
Venus
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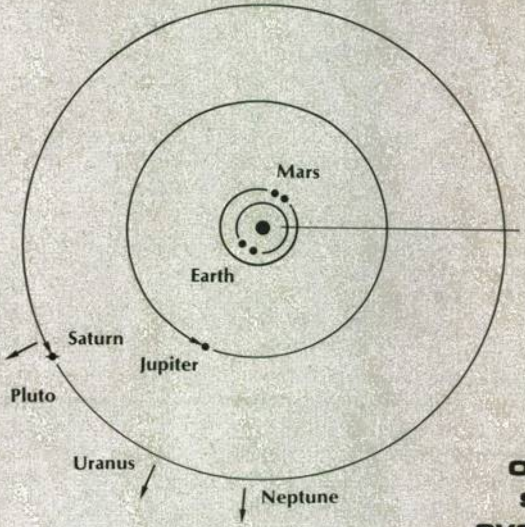

Mars
Earth
Saturn
Jupiter
Pluto
Uranus
Neptune

outer solar system

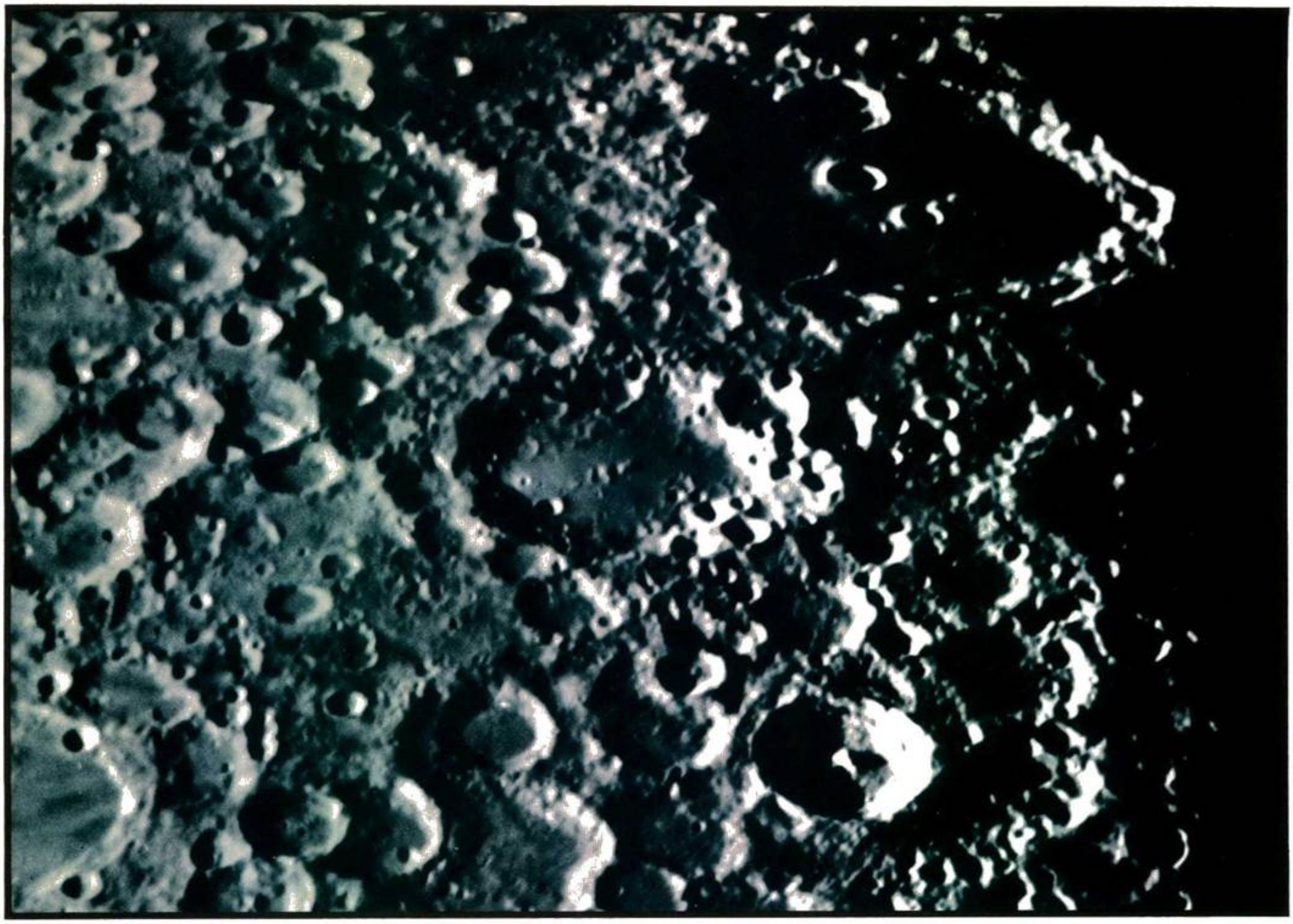
						Distance (AU) from:		Longitude:			
		Date	Mag.	Angular Size	% Illum.	Earth	Sun	Heliocentric	Ecliptic	R.A. (1983.4)	Dec.
Sun		1	−26.7	31.8′	—	1.01	—	—	40°04.4′	2h 30.6m	+14°50.1′
		15	−26.7	31.7′	—	1.01	—	—	53°37.4′	3h 24.9m	+18°40.7′
		31	−26.7	31.6′	—	1.01	—	—	69°00.4′	4h 29.2m	+21°48.0′
Mercury	☿	1	+1.7	10.1″	13%	0.66	0.41	194°21.4′	55°04.2′	3h 30.3m	+21°28.7′
		15	+3.2	12.1″	1%	0.55	0.46	237°58.0′	49°33.6′	3h 11.4m	+16°47.0′
		31	+1.3	9.8″	22%	0.69	0.46	282°31.6′	47°04.8′	3h 04.7m	+13°25.7′
Venus	♀	10	−3.6	16.8″	67%	1.00	0.72	160°21.8′	90°07.5′	6h 02.7m	+25°51.7′
		31	−3.8	20.1″	58%	0.84	0.72	194°22.4′	113°00.6′	7h 43.5m	+23°56.2′
Mars	♂	15	+1.6	3.7″	100%	2.51	1.50	62°03.1′	58°11.6′	3h 45.4m	+20°05.8′
Jupiter	♃	15	−2.1	45.1″	100%	4.37	5.36	245°02.9′	247°12.1′	16h 24.2m	−20°40.8′
Saturn	♄	15	+0.5	18.8″	100%	8.85	9.78	211°51.9′	208°58.4′	13h 53.4m	−8°43.7′
Uranus	♅	15	+5.8	3.8″	100%	17.96	18.94	246°56.5′	247°09.8′	16h 23.7m	−21°29.7′
Neptune	♆	15	+17.7	2.5″	100%	29.44	30.27	267°38.8′	268°13.4′	17h 54.6m	−22°10.3′
Pluto	♇	15	+13.7	0.1″	100%	29.09	29.89	208°20.1′	207°00.5′	14h 06.8m	+5°47.7′

moon data

Last Quarter. . . . . .May 5 at 3:43
New Moon . . . . .May 12 at 19:25
First Quarter. . . . . .May 19 at 14:17
Full Moon. . . . . .May 26 at 18:48
Last Quarter. . . . . .June 3 at 21:07
New Moon. . . . . .June 11 at 4:37
Apogee: May 4 at 13h. . . . . . .404,164 km.
Perigee: May 16 at 16h. . . . . . .367,518 km.

universal time

Astronomers the world over use an unambiguous system of time reckoning — Universal Time (UT) — based on a 24 hour clock. Times given in The Backyard Astronomer are UT unless noted otherwise. To convert UT into your local daylight time, subtract the following number of hours for each time zone: EDT, 4; CDT, 5: MDT, 6; PDT, 7; Alaska, 9. For example, if an event is to happen at 03:00 hours UT on June 7, then EDT for the event is 11 p.m., June 6. Likewise, 03:00 UT on September 2 becomes, in PDT, 8 p.m., September 1.



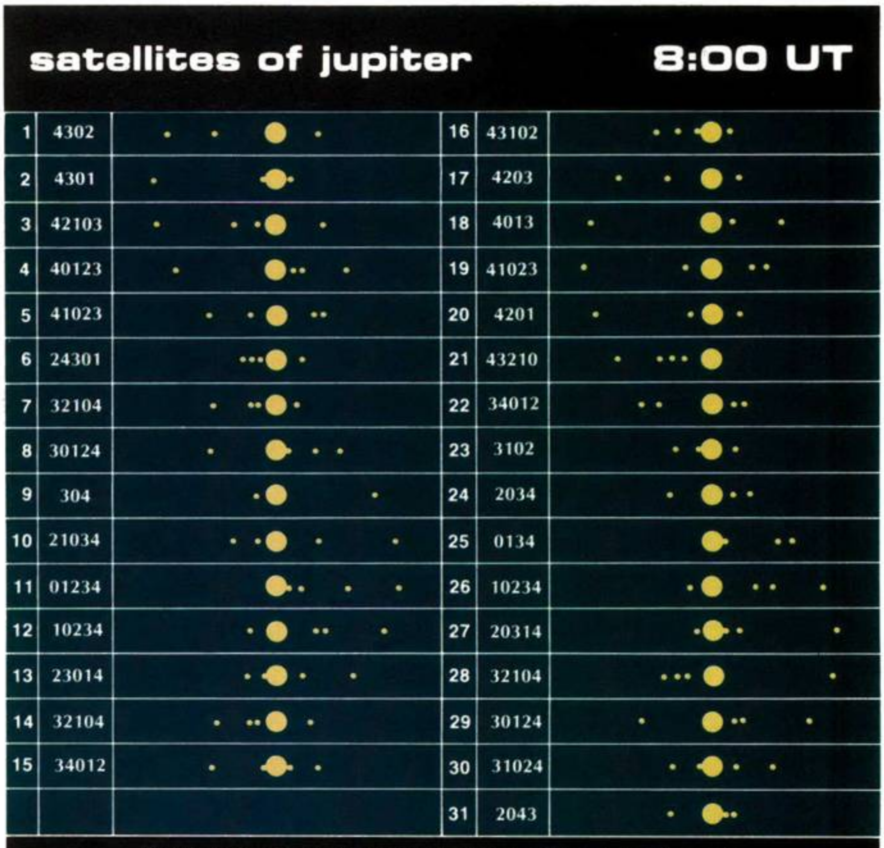
As the Sun rose over the 85-kilometer wide crater Tycho (bottom right) and the 225-km crater Clavius (top right), Jean Dragesco took their picture with a 14-inch SCT, eyepiece projection to f/40, and a 2-second exposure on 2415 film.

Quarter and will considerably diminish the number you'll see. In a good year you might expect 25 to 30 meteors per hour; this year there will probably be only half as many.

close-up on canes venatici

Canes Venatici, the Hunting Dogs, is a fairly new constellation, as constellations go. Asterion and Chara, the mythical dogs of the herdsman Bootes, first chased the Great Bear around the pole in 1690, the year Johannes Hevelius introduced the constellation. The region, which is fairly dim, contains no open star clusters and no diffuse or planetary nebulae. But Canes Venatici offers observers some interesting stars, a fine globular cluster, and galaxies aplenty.

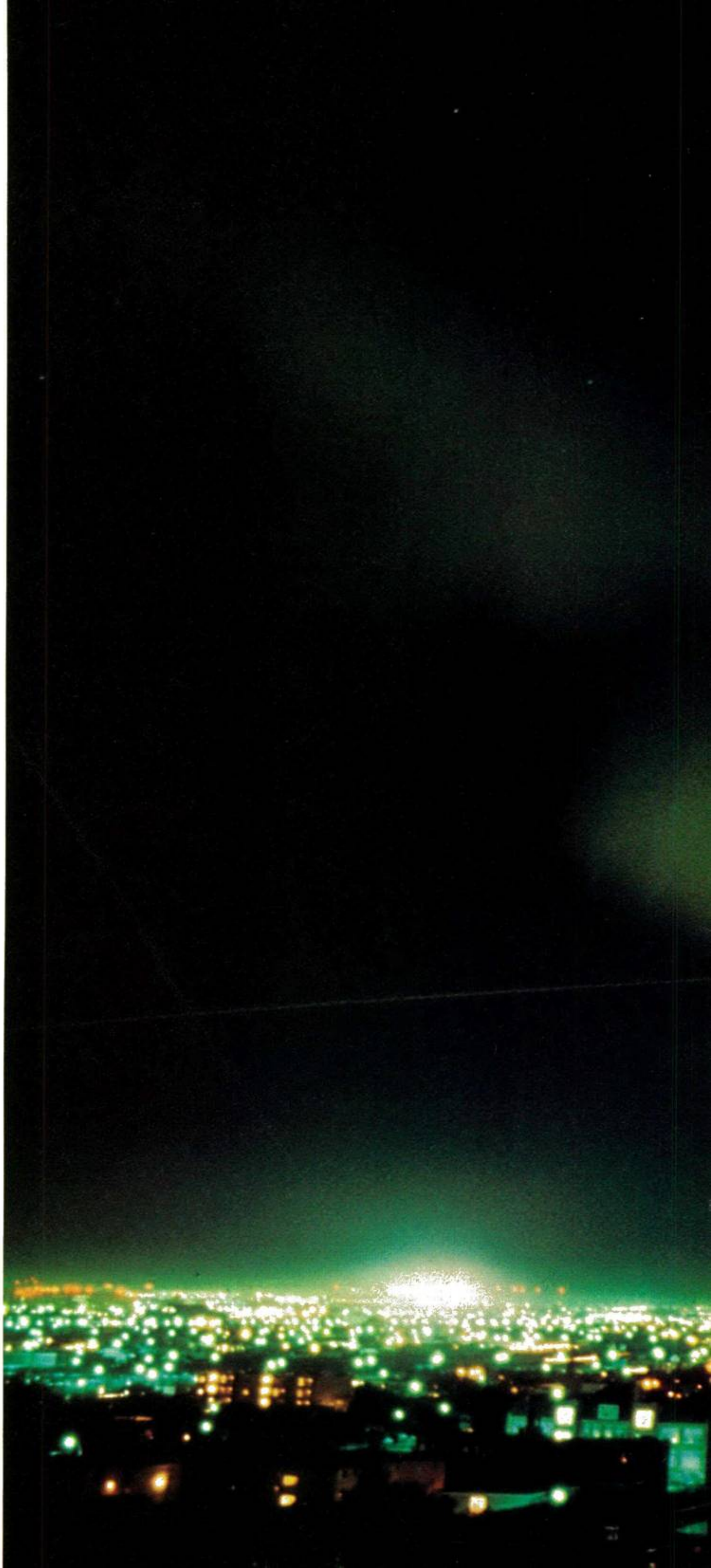
The brightest star of the constellation shines at magnitude 2.9 and marks the position of Chara, while Beta (β) Canum Venaticorum shows Asterion's place.



satellites of jupiter 8:00 UT

1	4302	16	43102
2	4301	17	4203
3	42103	18	4013
4	40123	19	41023
5	41023	20	4201
6	24301	21	43210
7	32104	22	34012
8	30124	23	3102
9	304	24	2034
10	21034	25	0134
11	01234	26	10234
12	10234	27	20314
13	23014	28	32104
14	32104	29	30124
15	34012	30	31024
		31	2043

Jupiter = 0, Io = 1, Europa = 2, Ganymede = 3, Callisto = 4
(South is at top, matching the view in a telescope)



This aurora over Edmonton, Alberta, was so bright that it recorded clearly, despite competition from a multitude of city lights. (The streak above the horizon is an airplane trail.) Alan Dyer used 200 ASA film, a 28 mm lens, and a 30-second exposure at f/3.5.

Alpha (α) CVn, also known as **Cor Caroli**, is an attractive double star for a small telescope, even though the color difference between its components is very slight — both the A0-type primary and its 5.4 magnitude F-type companion appear whitish. The pair is separated by 20″ of arc, which corresponds to about 770 AU at the accepted distance of 120 light-years. Cor Caroli is 80 times more luminous than Sol, while its companion shines with the brightness of seven Suns. Although no change in separation or position angle has ever been detected in this system, the stars are probably physically associated because they share a common proper motion and direction. Incidentally, Cor Caroli (Charles' Heart), is probably named after England's Charles I, who was executed in 1649.

Look about 5° to the northwest of Cor Caroli, and you might see a 4.8 magnitude star — the semi-regular variable **Y CVn**. The star lies in a rather unpopulated region of the constellation, about one-third of the distance between Cor Caroli and Delta (δ) Ursae Majoris. Y CVn is one of the reddest of all naked-eye stars, and a telescope really shows its remarkable tint.

The brightness of Y CVn varies between a minimum of about magnitude 6.3 to a maximum of magnitude 4.8 in about 160 days. The star's distance is not accurately known, so no one is certain about its physical size. But Y CVn's surface temperature is extremely low (about 2,600° Kelvin), thus its brightness can only be explained by assuming that the star has a large surface area. This variable is probably as large as the giant long-period variable Omicron (ο) Ceti (Mira).

At the southern extreme of Canes Venatici, about midway between Arcturus and Cor Caroli, lies one of the brightest globular clusters in the sky — **M-3**. Binoculars show it as a hazy sixth-magnitude "star," so this cluster ranks as one of the three brightest globulars in the northern sky. (M-13 in Hercules and M-5 in Serpens are the other members of the trio.) M-3 is about 38,000 light-years distant, and in it astronomers have counted more than 45,000 stars between magnitudes 11 and 22.5. Our Sun, if placed at this distance, would lie on the faint end of this range at magnitude 20.4. M-3 is about 10′ of arc in diameter, which corresponds to 220 light-years at the accepted distance. A good 6-inch telescope at fairly high power will resolve part of the cluster's milky haze into hundreds of stellar points.

M-3 also holds the record for the number of variable stars in a globular. Most of the 189 detected variables have

M-63, a bright spiral galaxy in Canes Venatici, is one of the objects featured this month in Close-up; Bill Iburg took its picture with a 14-inch SCT, a focal reducer, a cold camera, and 400 ASA film pushed to 800 ASA.

periods between 10 minutes to half a day and fall into a category known as RR Lyrae stars or "cluster variables." These stars are relatives of the well-known Cepheids and represent one of the most reliable means of determining intergalactic distances.

In spite of these attractions, galaxies are really the forte of this region. Near the constellation's northern border lies the famous **M-51**, or "Whirlpool Galaxy," about 3.5° southwest of Eta (η) Ursae Majoris, the last star in the handle of the Big Dipper. This face-on Sc-type spiral is about 35 million light-years away — so great a distance that its estimated diameter of 100,000 light-years appears only 10′ of arc across. The system's spiral structure can be glimpsed under good seeing with as little as 8 inches of aperture, but it takes 12 inches to show M-51's resemblance to the photographs that appear in almost every astronomy text.

Even in a relatively small telescope, M-51's satellite galaxy is conspicuous. Eleventh-magnitude **NGC-5195** is a small elliptical galaxy that appears to be attached to a warped spiral arm. Computer simulations of interacting galaxies suggest that this companion is moving behind M-51, directly into the plane of the sky.

About 5.5° southwest of the Whirlpool is an oval, 10th magnitude spiral — **M-63**. To find this Sb-type system, sweep an area roughly midway between Cor Caroli and Eta UMa. M-63 is about 9′ by 4′ in size and lies at roughly the same distance as M-51. This system is sometimes called the "Sunflower," presumably because its tightly wound, knotted arms resemble a giant celestial flower. Robert Burnham, Jr. notes, however, that the outer arms look more like "sparks thrown out by a rotating fiery pinwheel."

M-94, another bright galaxy, is easy to find because it lies midway between α and β CVn, about 1.5° above a line joining them. A very bright (magnitude 9), compact galaxy, the Sb-type spiral is remarkable for the brilliance of its central 30″ of arc. About 5′ of arc by 3.5′ in size, the longest dimension corresponds to a diameter of about 33,000 light-years at the accepted distance of 20 million light-years. The spiral pattern is well defined near the central "hub," where you might observe many dark splotches. These are enormous patches of dust that obscure the light of stars beyond them.

Just northeast of Beta Canum Venaticorum are two galaxies that may be interacting with each other. To find **NGC-4485** and **NGC-4490**, extend the line joining the constellation's brightest stars about 30′ of arc beyond Beta. NGC-4485, at magnitude 12.5, is either an irregular system or a peculiar elliptical, roughly 1.3′ by 0.7′ of arc in size. Only 3′ of arc south lies NGC-4490, a 10th magnitude Sc-type spiral about 5′ by 2′ of arc in size. Some astronomers claim that there is a stream of material joining the two systems. But this diagnosis of galactic interaction is questionable because NGC-4485 and 4490 have very different redshifts.

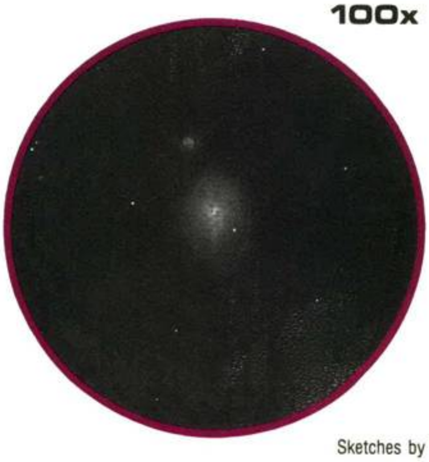
Farther north, about midway between Gamma (γ) UMa and Beta CVn on the line connecting them, the bright spiral **M-106** glows amid a group of fainter galaxies. An Sb system, M-106 is a ninth-magnitude object about 20′ by 6′ of arc in size. Spiral structure may be difficult to see — good seeing and at least 10 inches of aperture are necessities. You can use M-106 as a reference to locate the three nearby 12th magnitude galaxies. The members of this trio all lie within about 40′ of arc from M-106: **NGC-4220** to the northeast (type Sc, about 3′ by 0.9′ of arc in size), **NGC-4217** to the southeast (type S0, 5′ by 1.4′ of arc), and **NGC-4346** to the southwest (a barred spiral, 2.3′ by 0.9′ of arc).

The edge-on spiral **NGC-4244** makes an interesting finale for an evening of galaxy hunting in Canes Venatici. Located about 5° southeast of Beta CVn, this system shows little detail — just a slender, 11th magnitude streak, 13′ by 1′ of arc in size, with a somewhat brightened center. You'll need at least 10 inches of aperture to get a good view of this object.

The Hunting Dogs has a lot to offer galaxy enthusiasts. The weather is warm, the spring skies clear — there's no excuse for passing up a prowl or two through Canes Venatici. The objects listed here are only a few of the best and the brightest of the region, so sweep around — explore! Take the time to tour this rich galaxy hunting-ground with a star atlas and a friend.

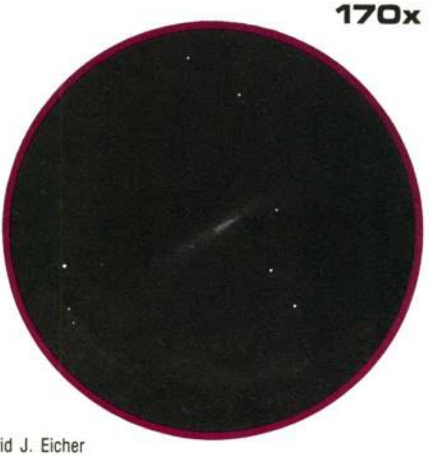
M-51

8-inch reflector 100x



NGC-4244

8-inch reflector 170x

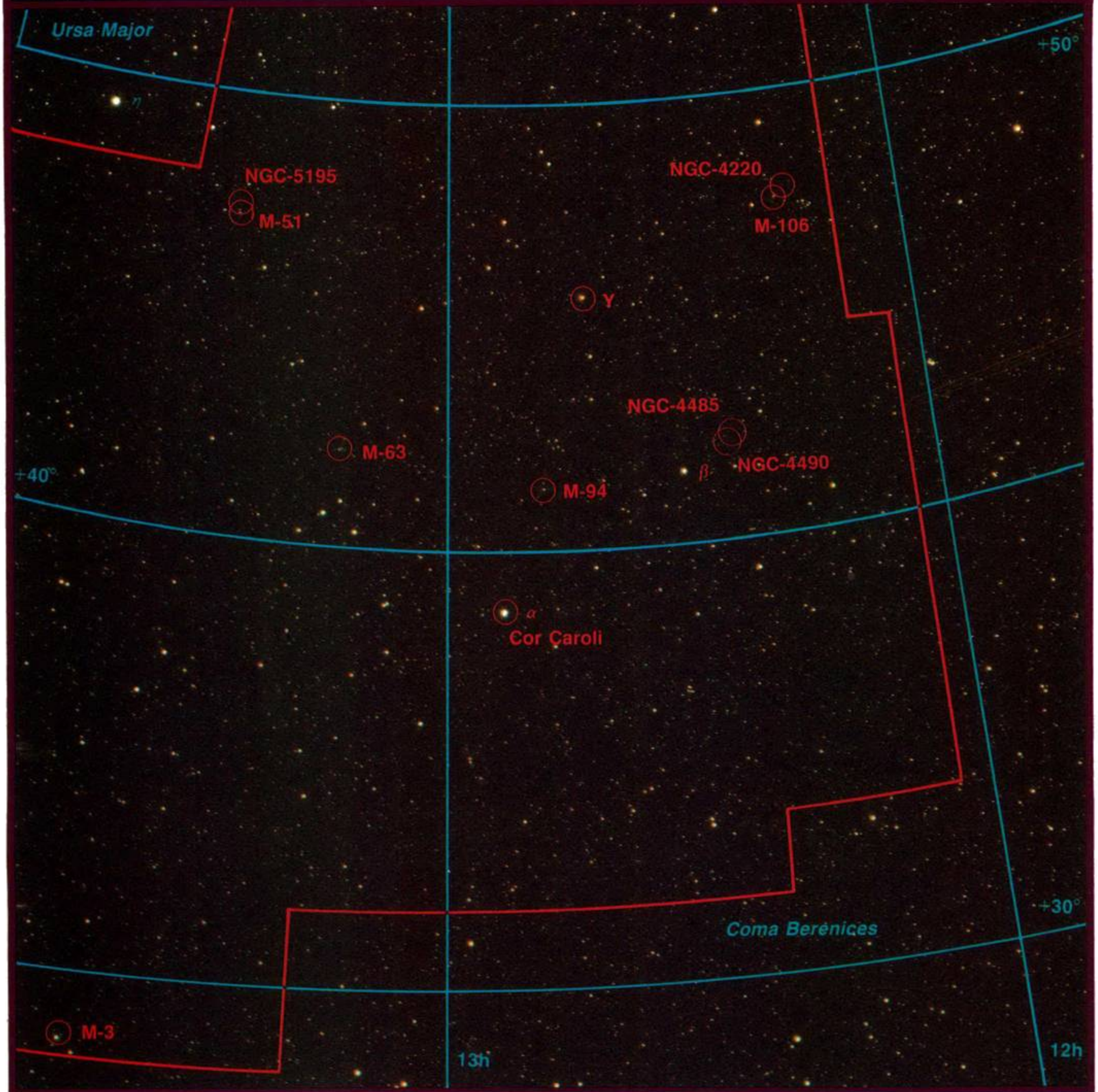


Sketches by David J. Eicher

Photo by Robert Provin and Brad Wallis

canes venatici

Map by Francis Reddy


Ursa Major
η
+50°
NGC-5195
M-51
NGC-4220
M-106
Y
NGC-4485
M-63
+40°
β
NGC-4490
M-94
α
Cor Caroli
+30°
Coma Berenices
M-3
13h
12h

Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.	R.A. (2000)	Dec.
NGC-4220	§	12.4	3.0′x0.9′	12h 14m	+48°10′	12h 16m	+47°53′
M-106	§	10.2	18.6′x7.6′	12h 17m	+47°35′	12h 19m	+47°18′
NGC-4485	§	12.9	1.8′x1.1′	12h 28m	+41°58′	12h 31m	+41°41′
NGC-4490	§	10.5	5.4′x2.7′	12h 28m	+41°55′	12h 31m	+41°38′
Y	SRV	4.8-6.3	160d	12h 43m	+45°43′	12h 45m	+45°27′
M-94	§	9.0	7.4′x5.9′	12h 49m	+41°23′	12h 51m	+41°07′
Cor Caroli	★²	2.9+5.6	20″	12h 54m	+38°35′	12h 56m	+38°19′
M-63	§	10.5	9.0′x4.0′	13h 14m	+42°17′	13h 16m	+42°01′
M-51	§	8.9	10.7′x7.0′	13h 28m	+47°27′	13h 30m	+47°12′
NGC-5195	#	10.5	2.0′x1.5′	13h 28m	+47°31′	13h 30m	+47°16′
M-3	●	7.0	10.0′	13h 40m	+28°38′	13h 42m	+28°23′

★	*Star*
★²	*Double Star*
★³	*Triple Star*
RV	*Regular Variable*
IV	*Irregular Variable*
EV	*Eclipsing Variable*
⊙	*Open Cluster*
●	*Globular Cluster*
■	*Planetary Nebula*
□	*Bright Diffuse Nebula*
0	*Elliptical Galaxy*
§	*Spiral Galaxy*
∮	*Barred Spiral Galaxy*
#	*Peculiar/Irregular Galaxy*

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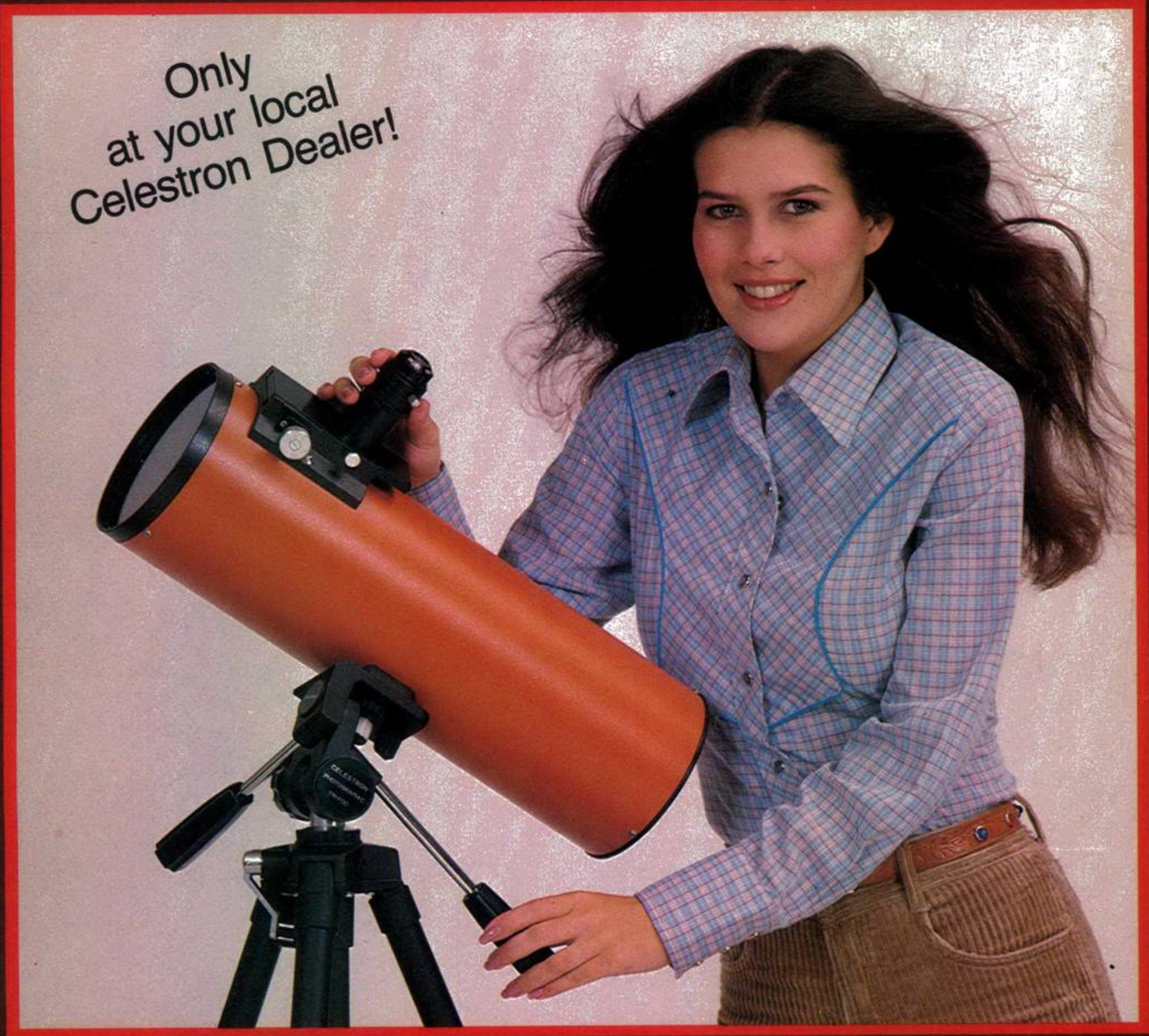

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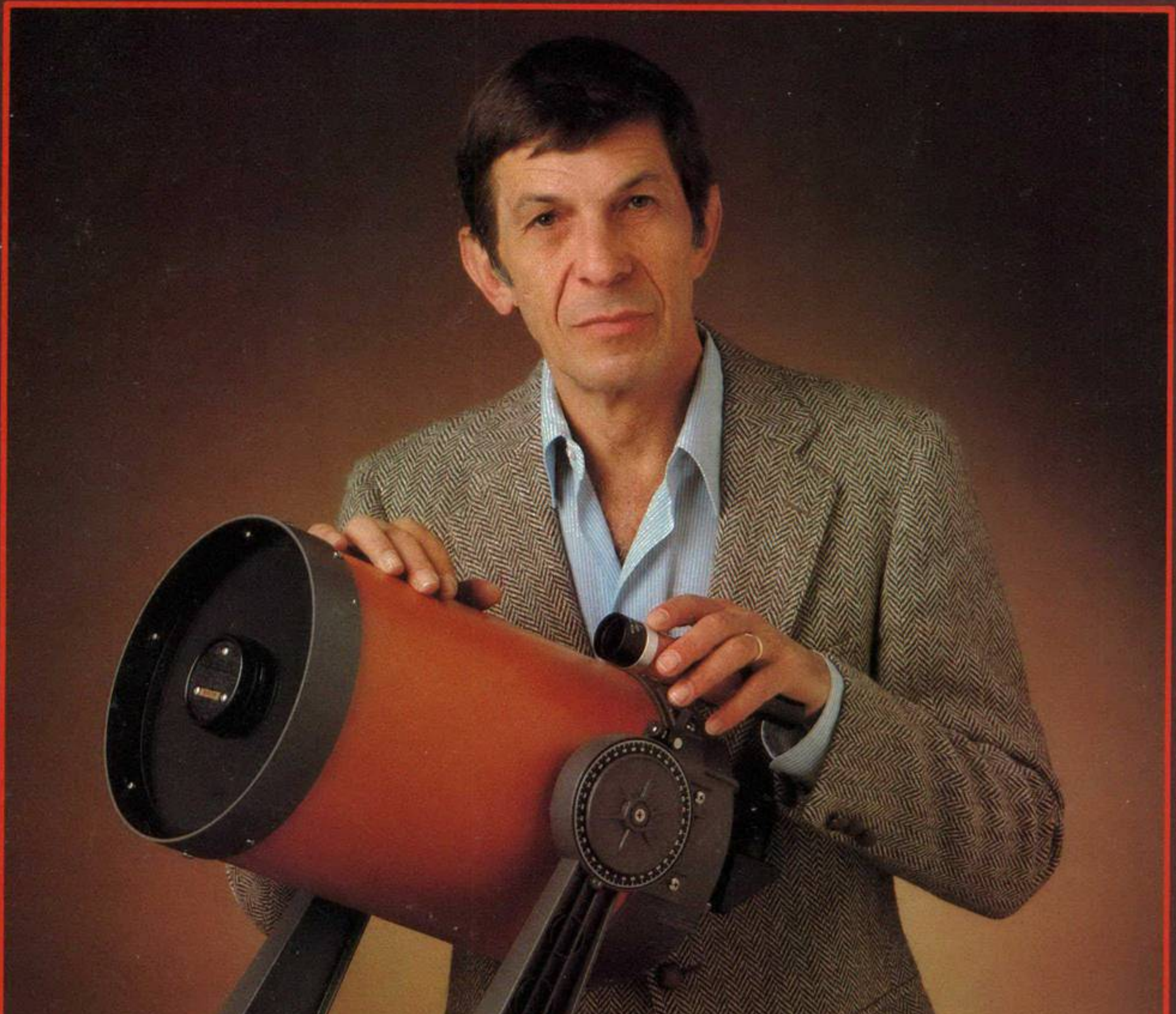

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